TAS Code Results for the Third High Lift Prediction Workshop

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PID: 011

3rd High Lift Prediction Workshop
Denver, CO June 3-4, 2017

Summary of cases completed: TAS code

Case	Alpha=8, Fully turb, grid study	Alpha=16, Fully turb, grid study	Other
1a (full gap)	YES	YES	
1b (full gap w adaption)	NO	NO	
1c (partial seal)	NO	NO	
1d (partial seal w adaption)	NO	NO	

Turbulence model:
SA-noft2-R (C_{rot} = 1)

Case	Polar, Fully turb	Polar, specified transition	Polar, w transition prediction	Other
2a (no nacelle)	YES	NO	NO	
2b (no nacelle w adaption)	NO	NO	NO	
2c (with nacelle)	YES	NO	NO	
2d (with nacelle w adaption)	NO	NO	NO	

Case	2D Verification study	Other
3	YES	

Summary of cases completed: TAS code

Case	Alpha=8, Fully turb, grid study	Alpha=16, Fully turb, grid study	Other
1a (full gap)	YES	YES	
1b (full gap w adaption)	NO	NO	
1c (partial seal)	NO	NO	
1d (partial seal w adaption)	NO	NO	

Turbulence model:
SA-noft2-R-QCR2000 (C_{rot} = 1)

Case	Polar, Fully turb	Polar, specified transition	Polar, w transition prediction	Other
2a (no nacelle)	YES	NO	NO	
2b (no nacelle w adaption)	NO	NO	NO	
2c (with nacelle)	YES	NO	NO	
2d (with nacelle w adaption)	NO	NO	NO	

Case	2D Verification study	Other
3	NO	

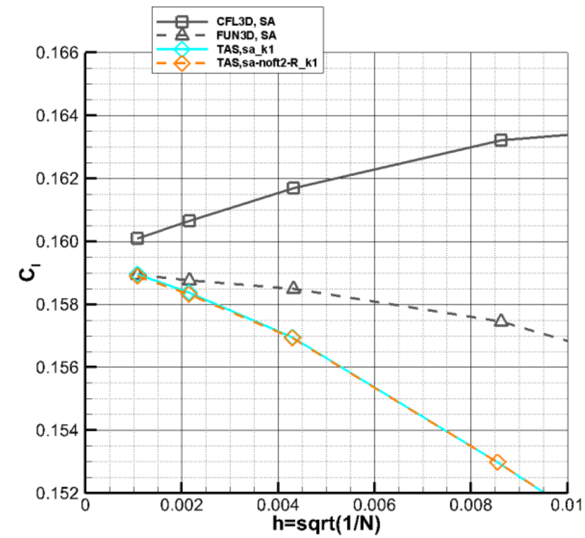
Summary of code and numerics used

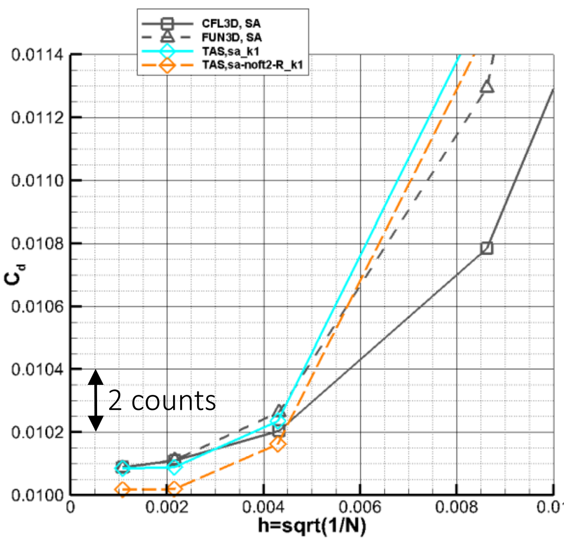
- TAS (Tohoku Univ. Aerodynamic Simulation) code
  - Unstructured hybrid RANS solver
  - Originally developed by Nakahashi *et al*.
- Quadratic Constitutive Relation (QCR) by Spalart
  - Well predicting side-of-body separation in transonic flows based on our previous experience (*e.g.*, Yamamoto *et al*., AIAA Paper 2010-4222).
  - Evaluated for high-lift cases in this study (also evaluated in HiLiftPW-2).

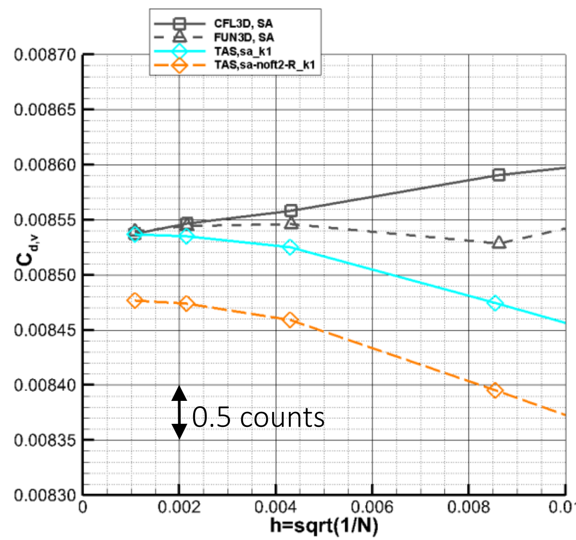
	TAS code
Grid type	Unstructured hybrid grids
Discretization	Cell-vertex finite volume
Convection flux	HLLEW 2nd-order with Venkatakrishnan's limiter
Time integration	LU-Symmetric Gauss-Seidel
Turbulence model	SA-noft2-R (C_{rot} = 1) (***QCR off***) or SA-noft2-R-QCR2000 (C_{rot} = 1) (***QCR on***)

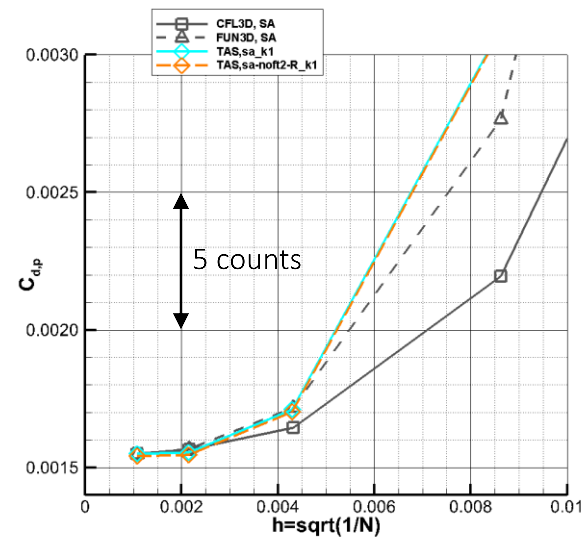
Case 3 Verification study results

- Based on the finest mesh,
  - Compared w FUN3D + SA, TAS code + SA predicts similar C_l & C_d.
  - TAS code + SA-noft2-R (C_{rot} = 1) predicts smaller C_d than TAS code + SA by 0.6 drag counts mostly because of the difference in $C_{d,v}$.

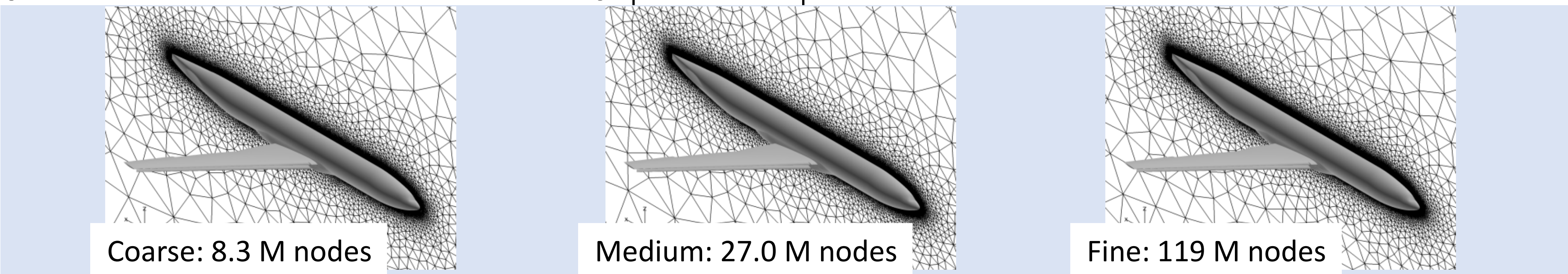
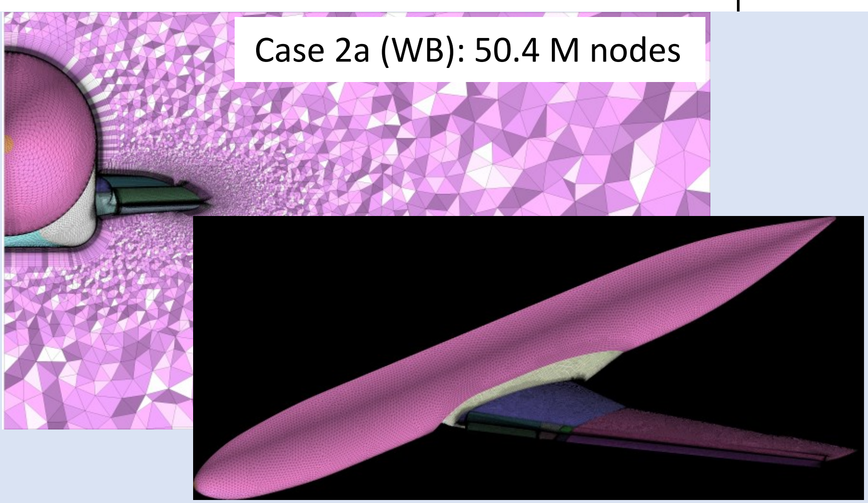


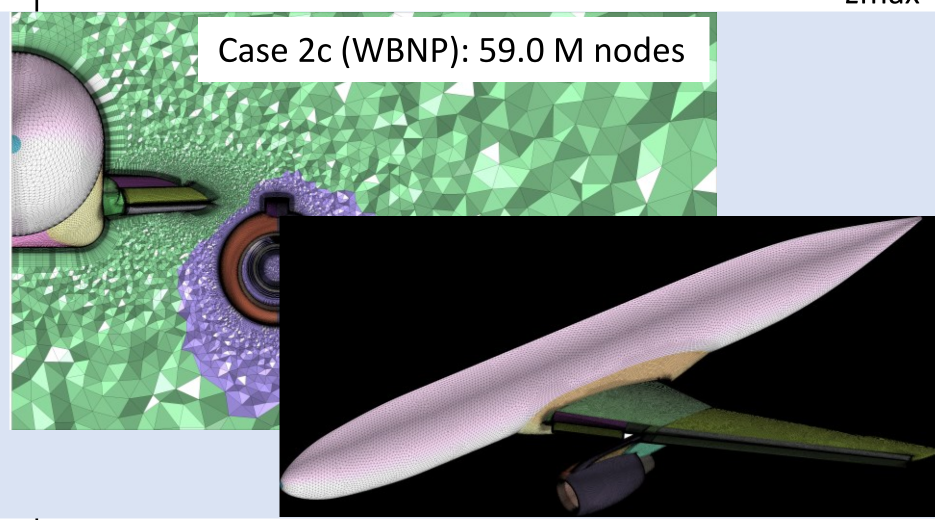






Brief overview of grid systems

<table>
<tr><th>Grid System</th><th>Case(s)</th><th>Problems/Issues</th></tr>
<tr><td>Committee
(B3-HLCRM_UnstrHexPrismPyrTet_PW)</td><td>1a</td><td>Grid quality OK
Submitted feedback</td></tr>
<tr><td colspan="3">
</td></tr>
<tr><td>Committee
(D-JSM_UnstrMixed_JAXA)</td><td>2a
2c</td><td>Wing deformation effect?
Mesh resolution enough to predict C_{Lmax}?</td></tr>
<tr><td colspan="3">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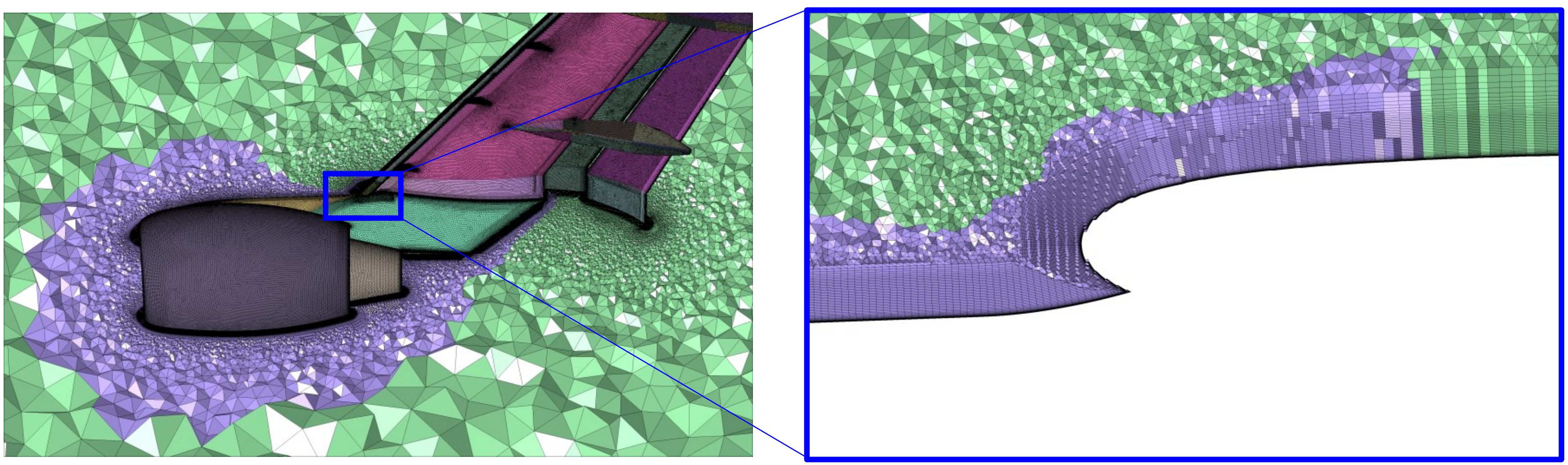
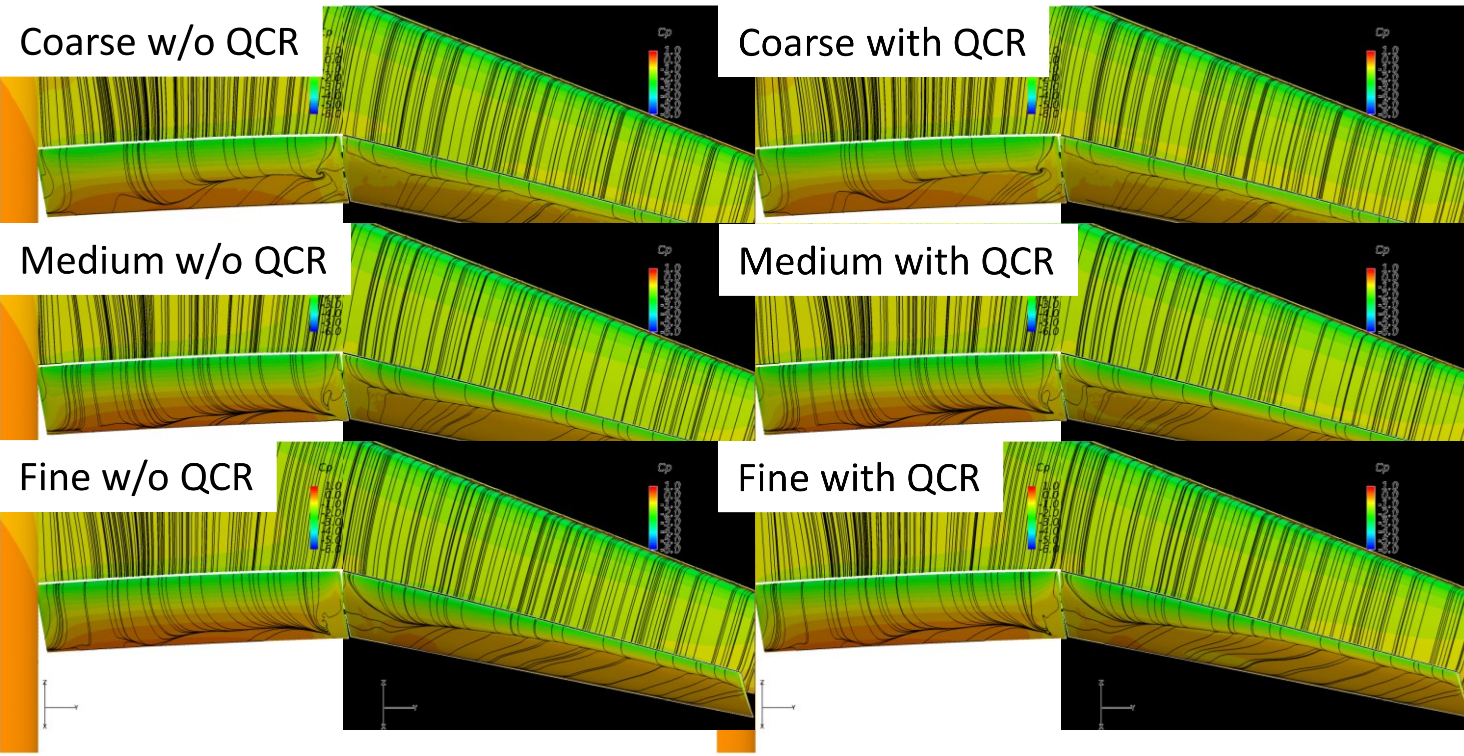
MEGG3D – Mixed Element Grid Generator in 3D

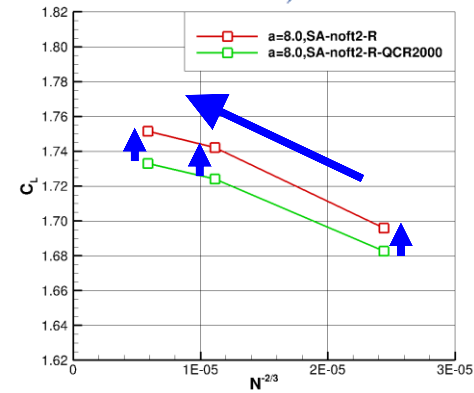
- Unstructured hybrid surface/volume grid generator (prisms, hexes, tets & pyramids)
- The **Automatic Local Remeshing** enabled to reuse a volume grid generated around a baseline geometry (in this case, WB) when an additional geometry (NP) was inserted.
  - New grids were generated automatically.
  - The same elements were used except those around the additional geometry, so that its effect can be evaluated more precisely.

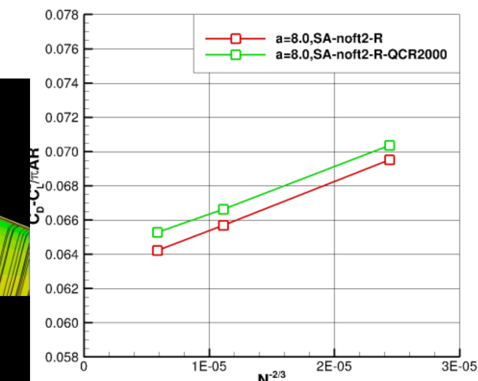


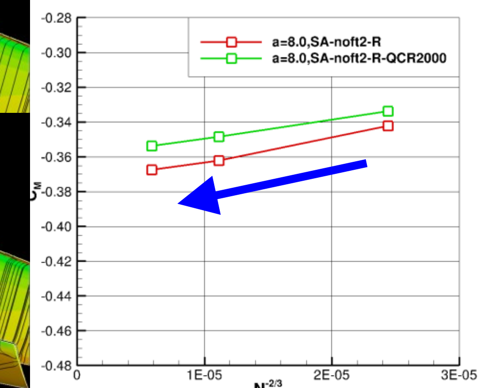
Case 1a HL-CRM $\alpha = 8°$

- Large flow separation predicted on the flaps.
- Smaller flow separation on the flaps with a finer mesh. → Lager C_L & smaller C_M
- Slightly smaller flow separation predicted by the cases w/o QCR.



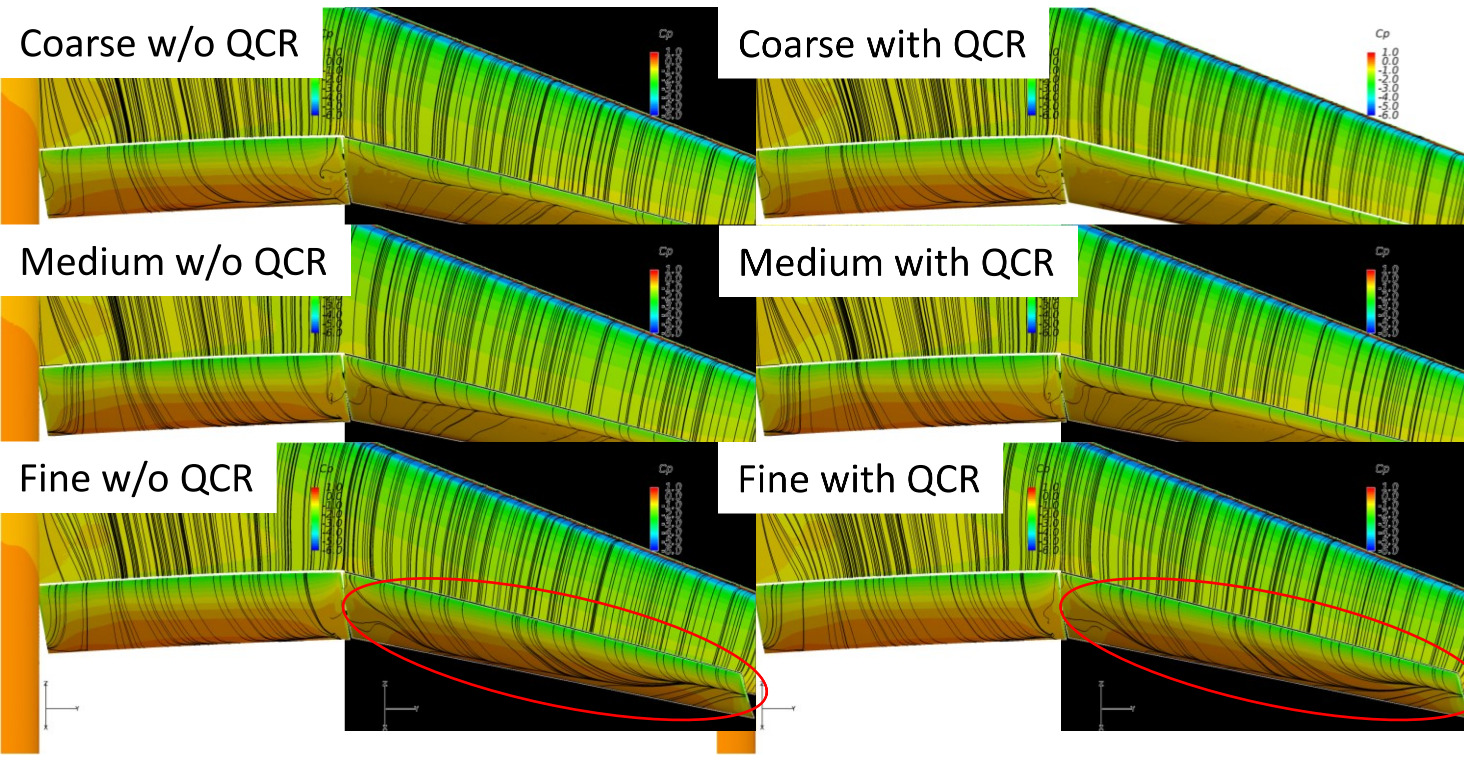


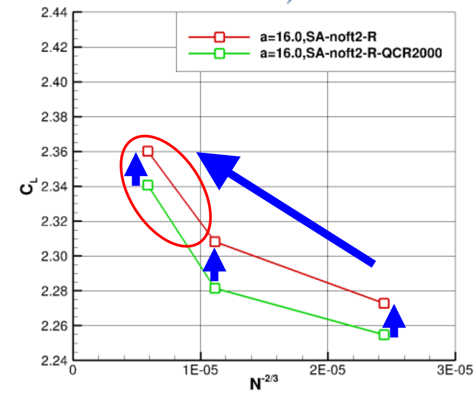


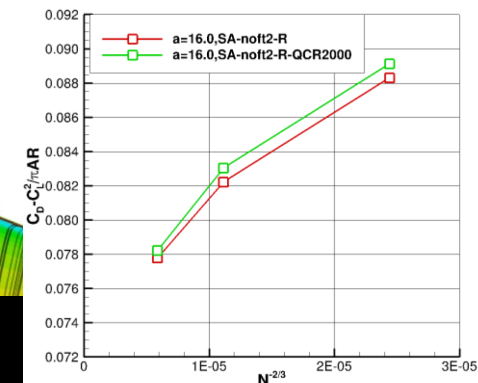


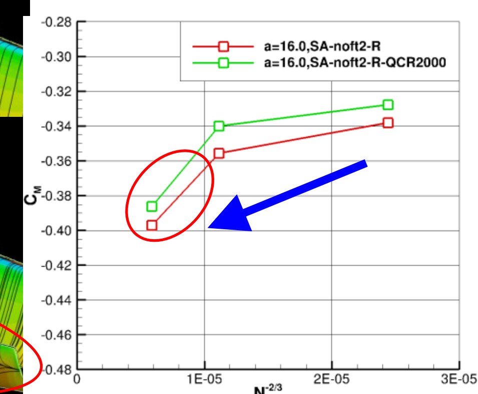
Case 1a HL-CRM α = 16°

- Smaller flow separation predicted by a finer mesh and by SA w/o QCR.
- With the fine mesh, flow separation almost disappears on the inboard flap & small flow separation on the outboard flap.



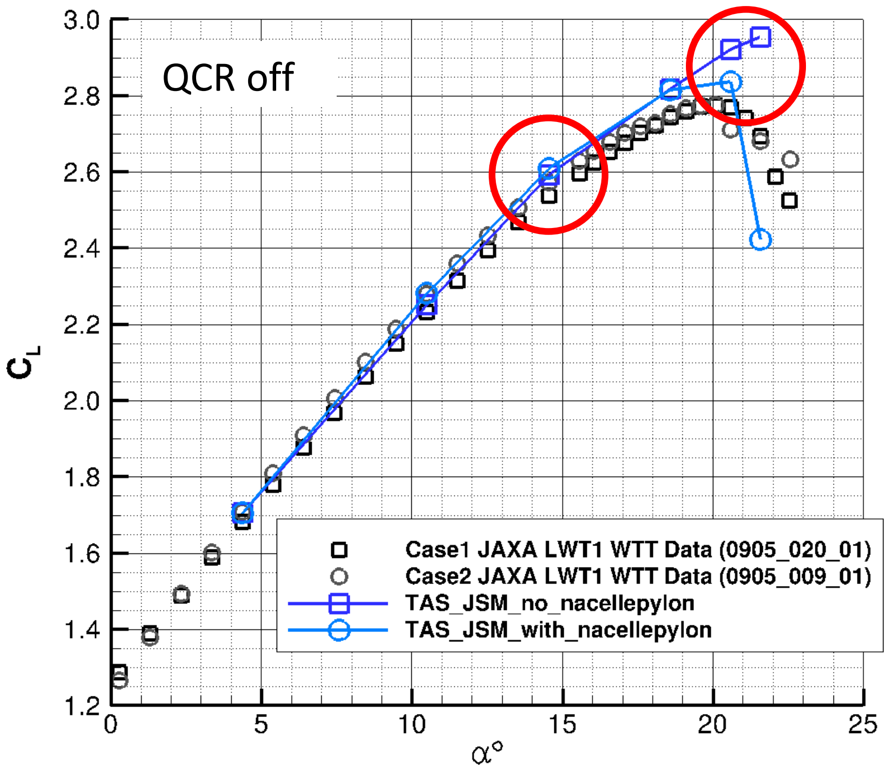


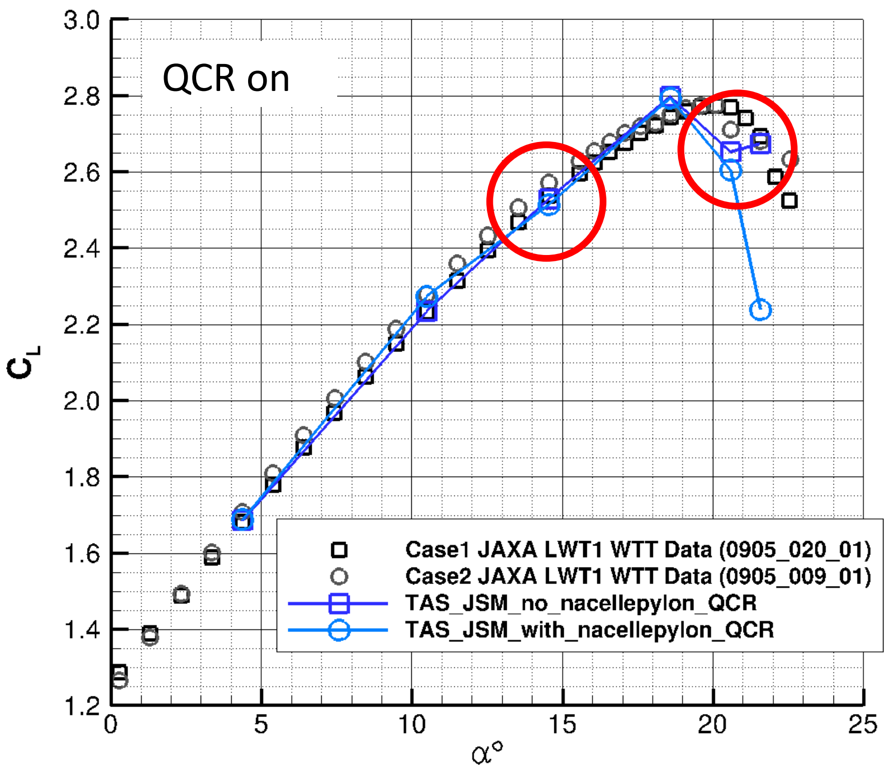




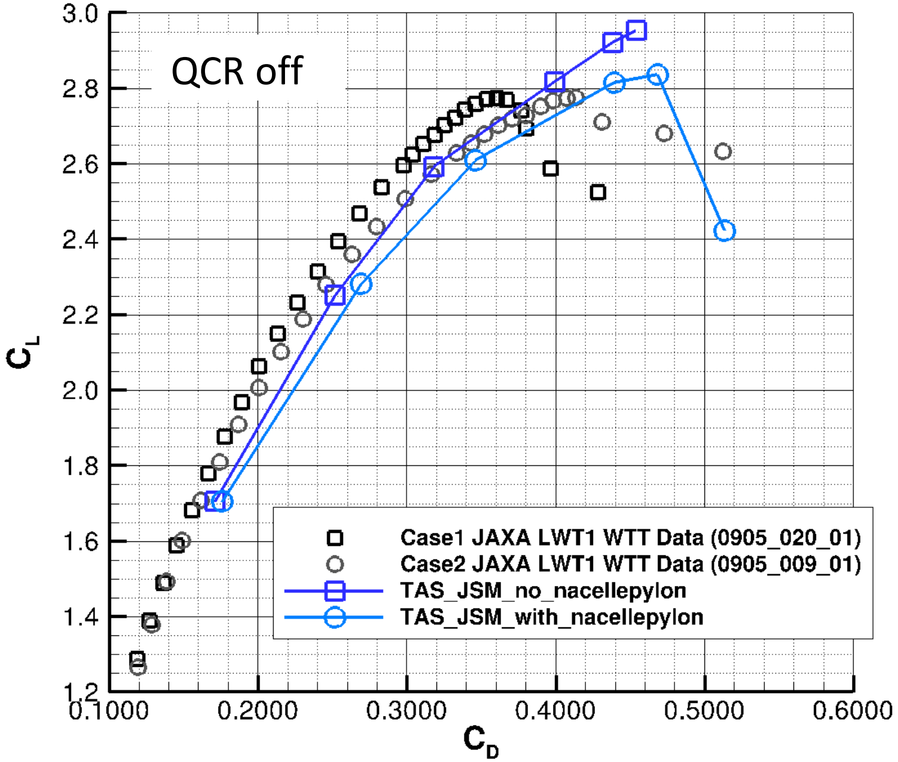
Cases 2a & 2c JSM C_L-α

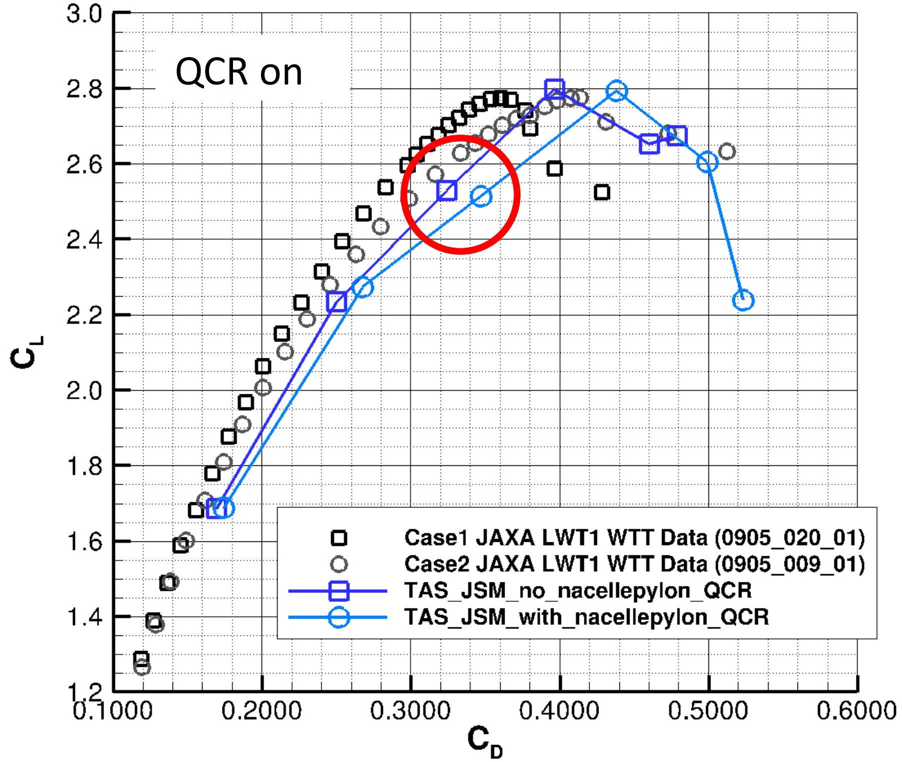
- Difference in CL at high α due to larger flow separation on the outboard wing when QCR is turned on.



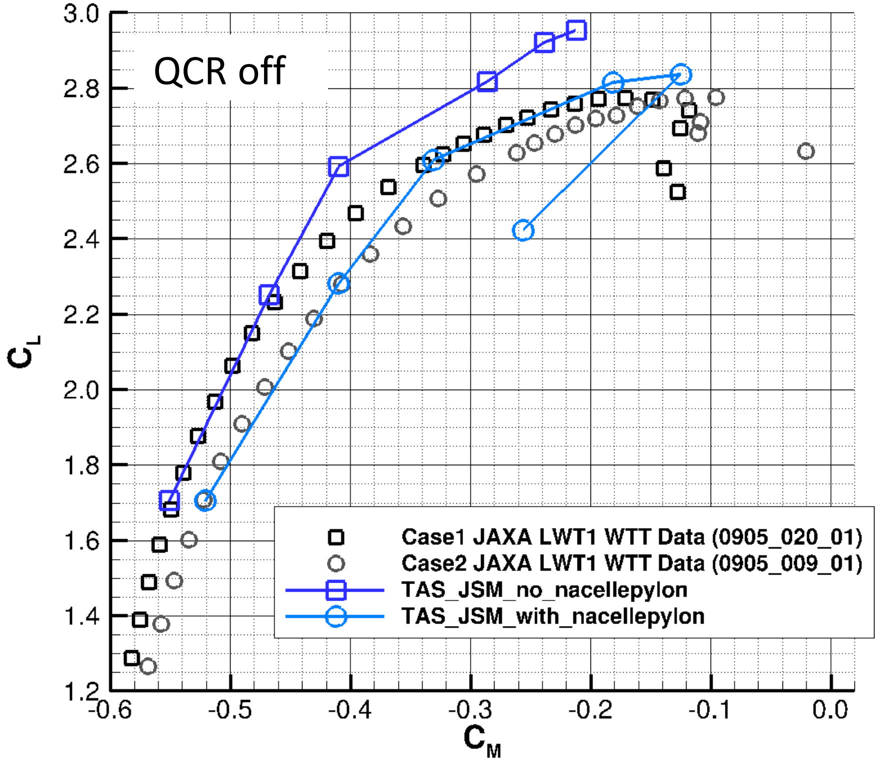


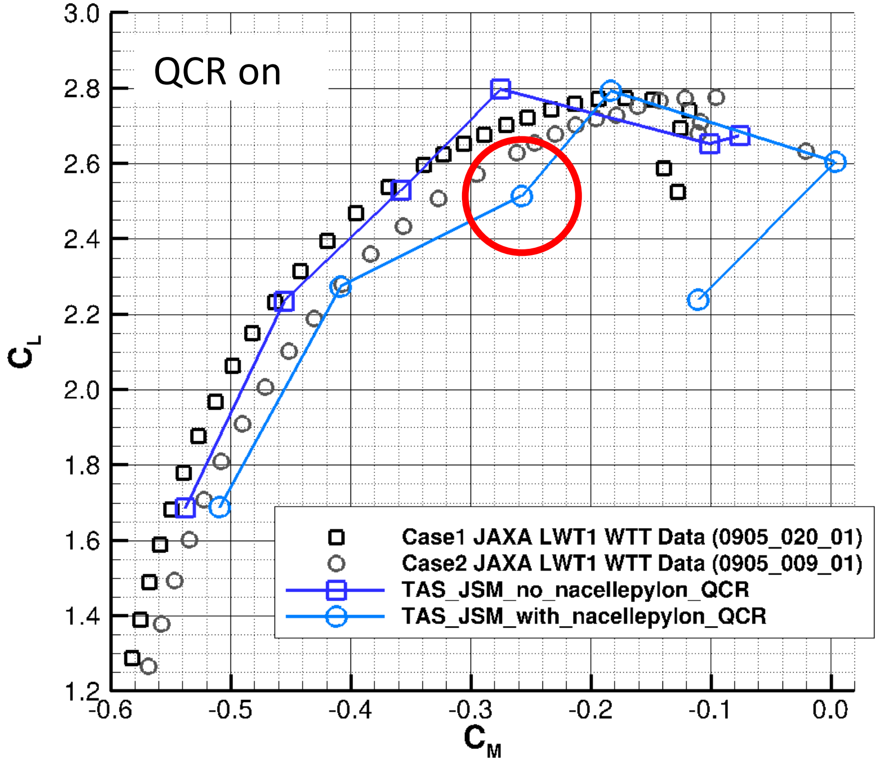
Cases 2a & 2c – JSM C_L-C_D





Cases 2a & 2c – JSM C_L-C_M



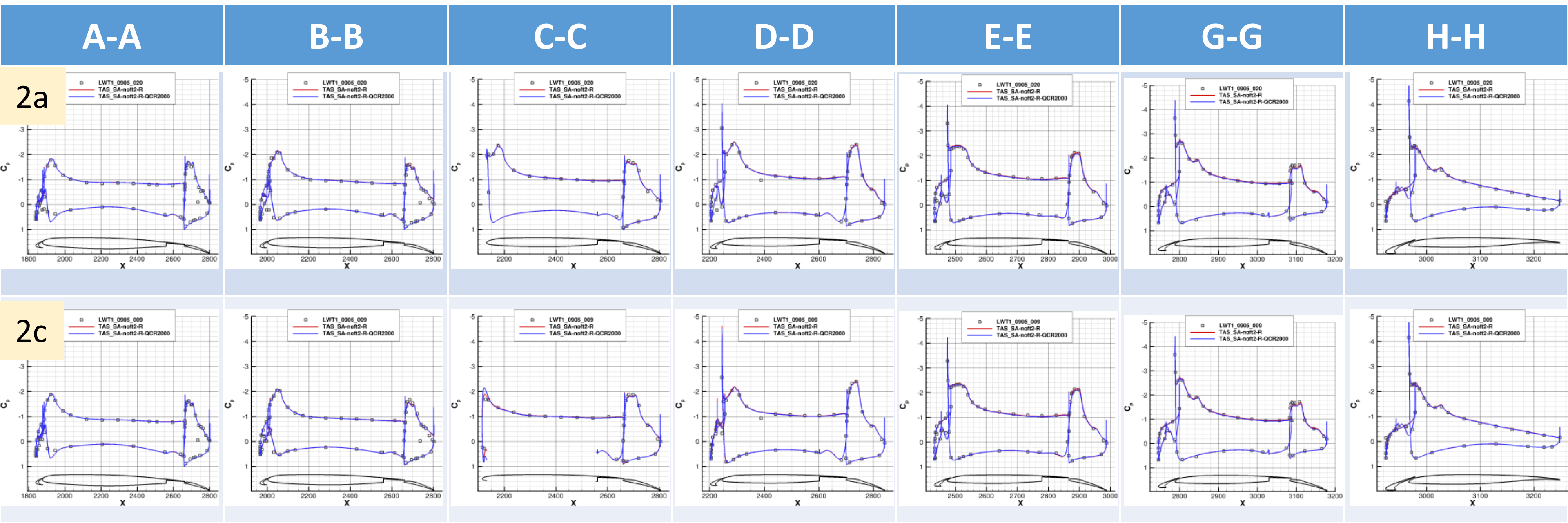


Cases 2a & 2c – JSM C_p α = 4.36°

- Both QCR on/off mostly agree well with experiment.
- QCR on predicts flow separations slightly larger (not visible in the Cp graphs).
- Compared with experiment, a similar tendency was observed at α = 10.47°.

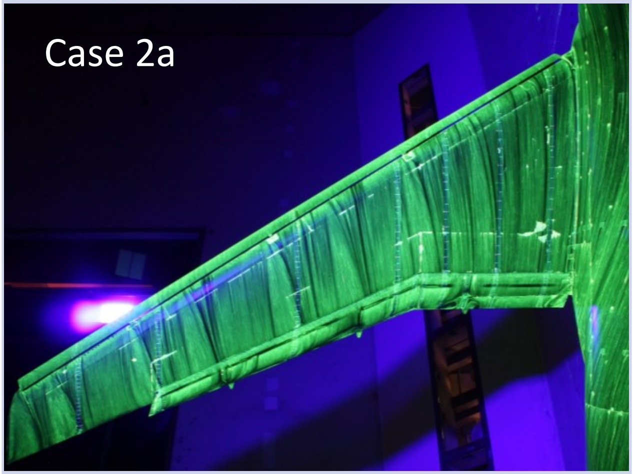
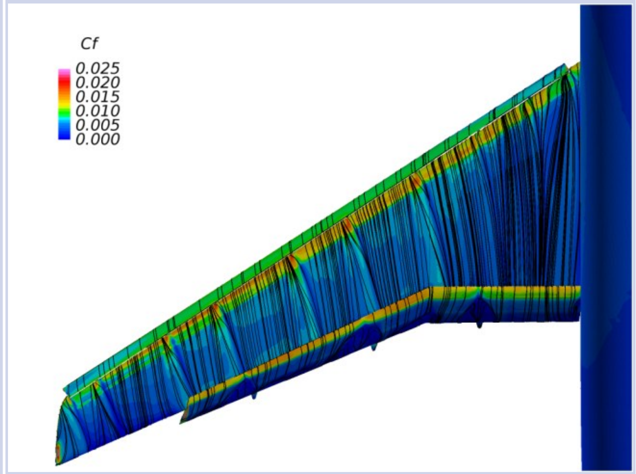
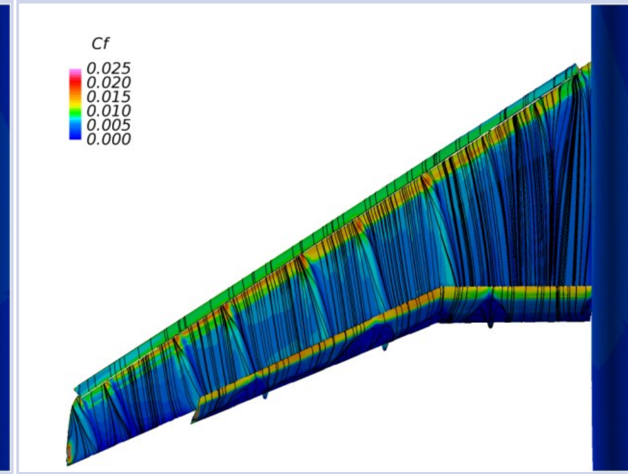
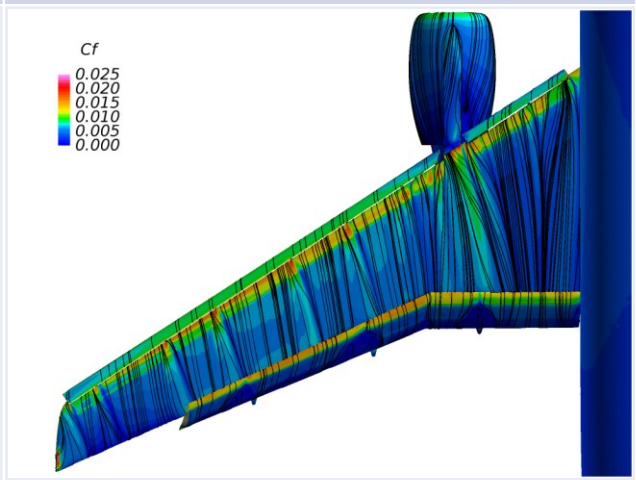
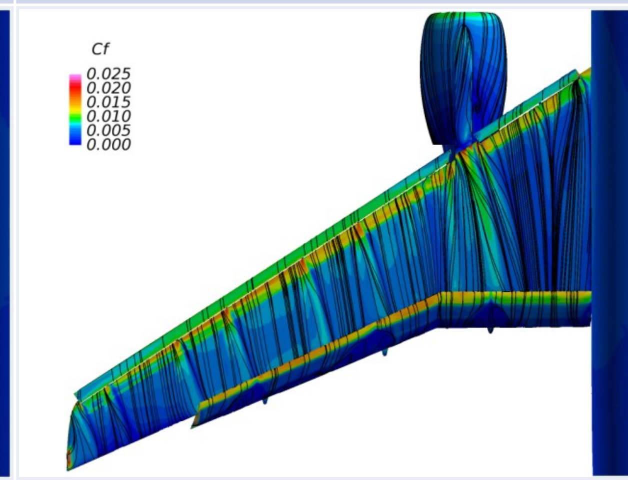
QCR off

QCR on



Cases 2a & 2c – JSM α = 4.36°

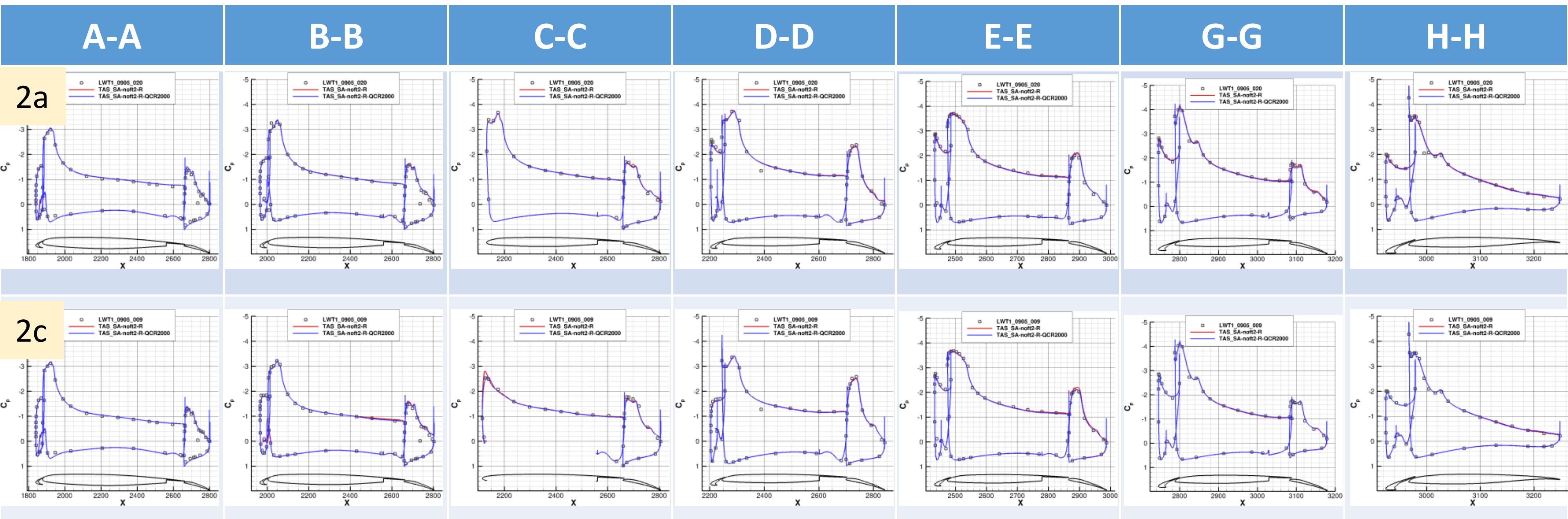
- Similar oil flow images

Exp	QCR off	QCR on
		
		

Cases 2a & 2c – JSM C_p $\alpha = 10.47°$

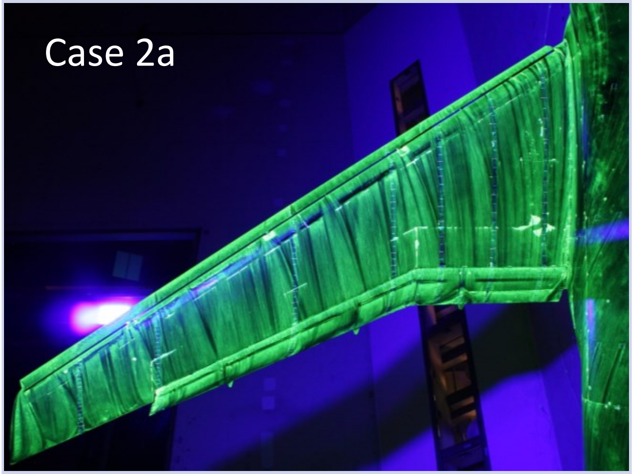
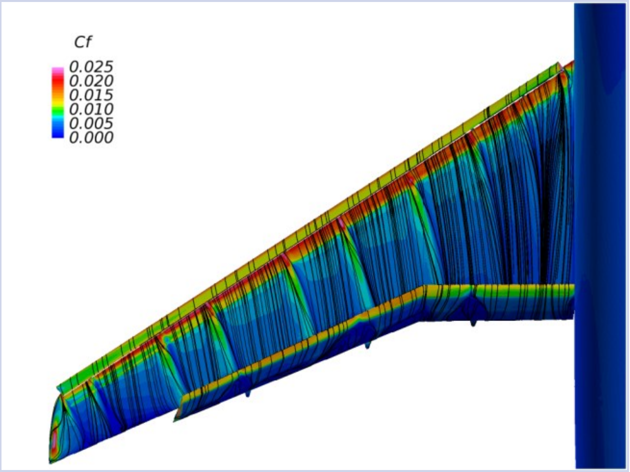
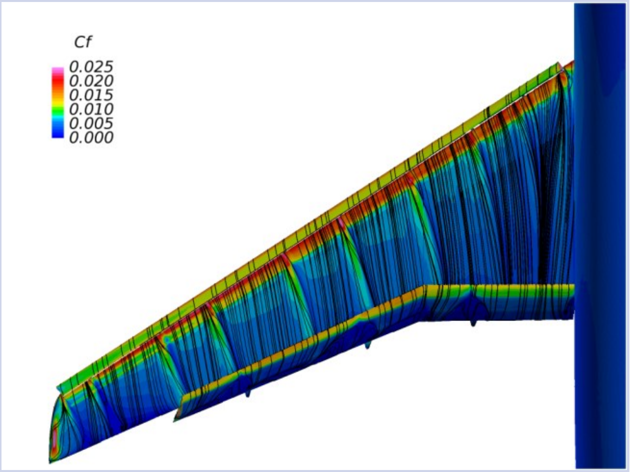
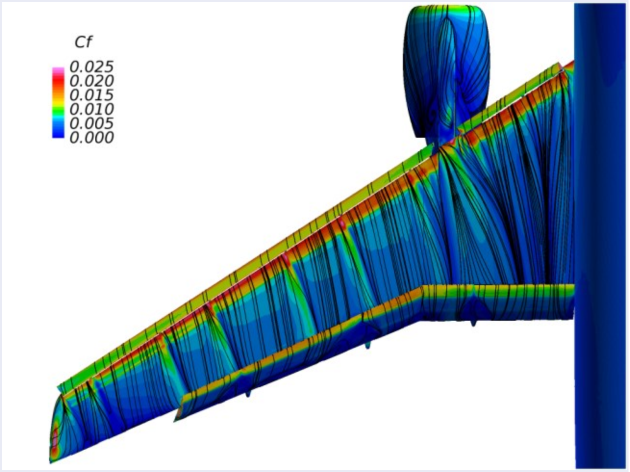
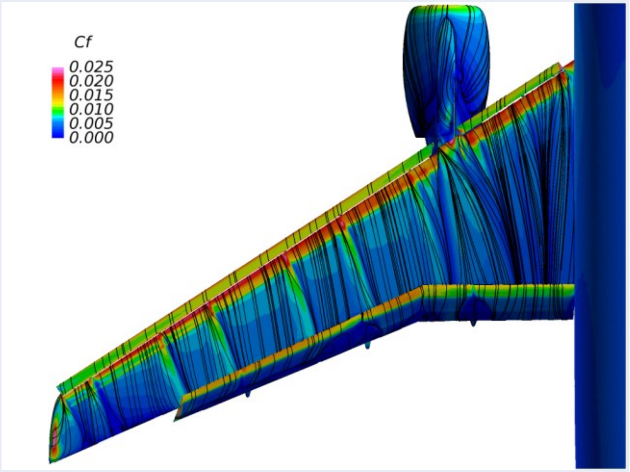
- Both QCR on/off mostly agree well with experiment.

QCR off
QCR on



Cases 2a & 2c – JSM α = 10.47°

- Similar oil flow images

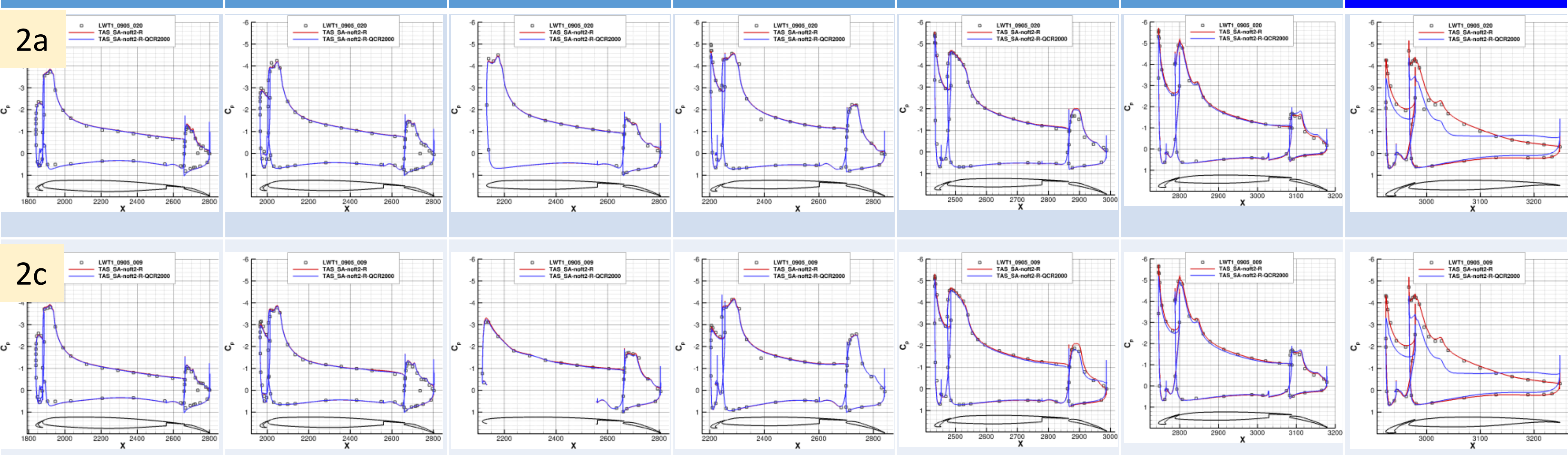
Exp	QCR off	QCR on
		
		

Cases 2a & 2c – JSM C_p $\alpha = 14.54°$

- QCR on/off predict similar Cp distributions except at the outboard section.
- QCR off agrees better with experiment even at H-H section.

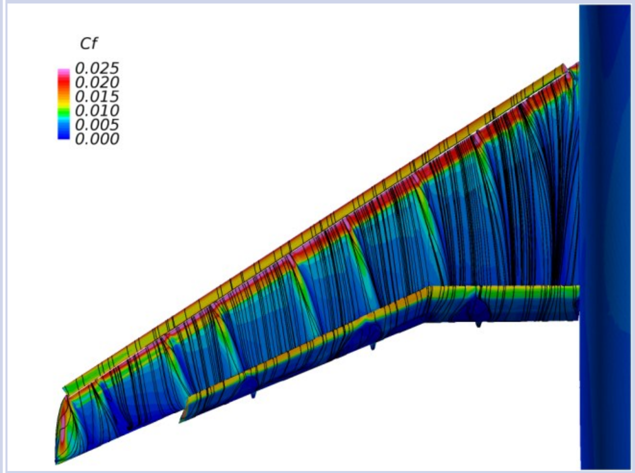
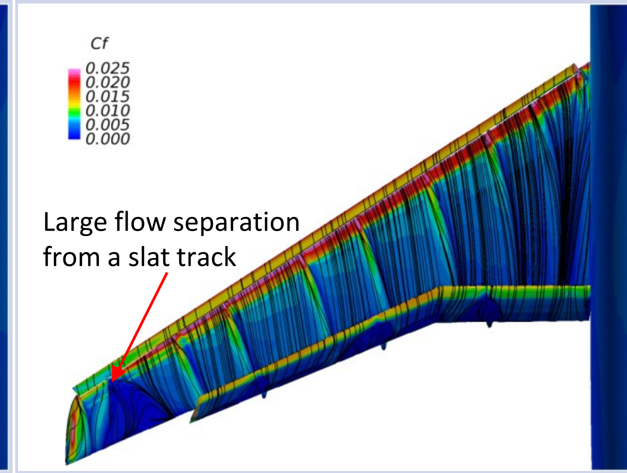
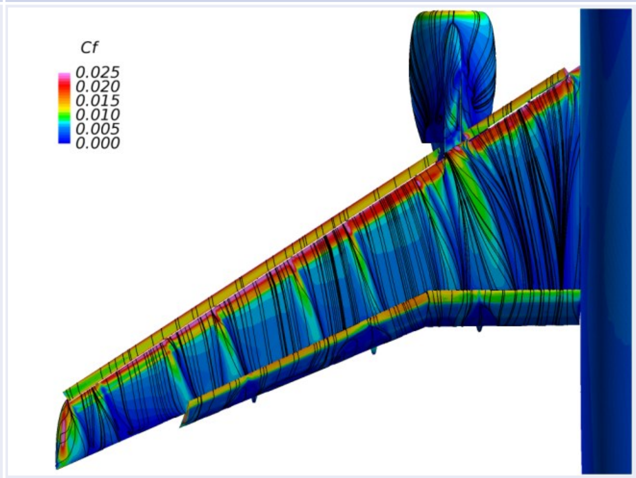
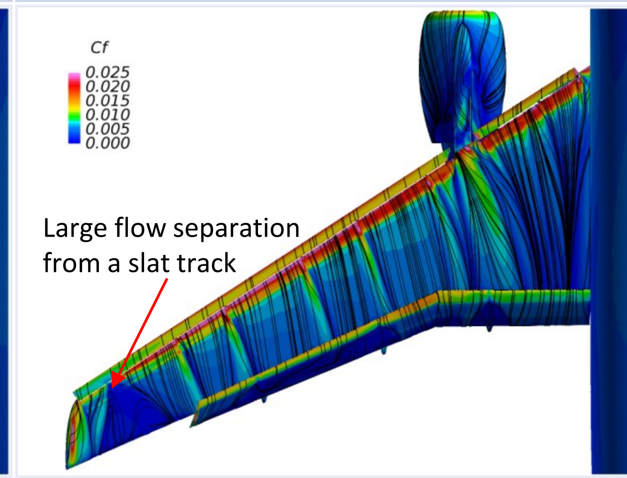
QCR off
QCR on

	A-A	B-B	C-C	D-D	E-E	G-G	H-H



Cases 2a & 2c – JSM α = 14.54°

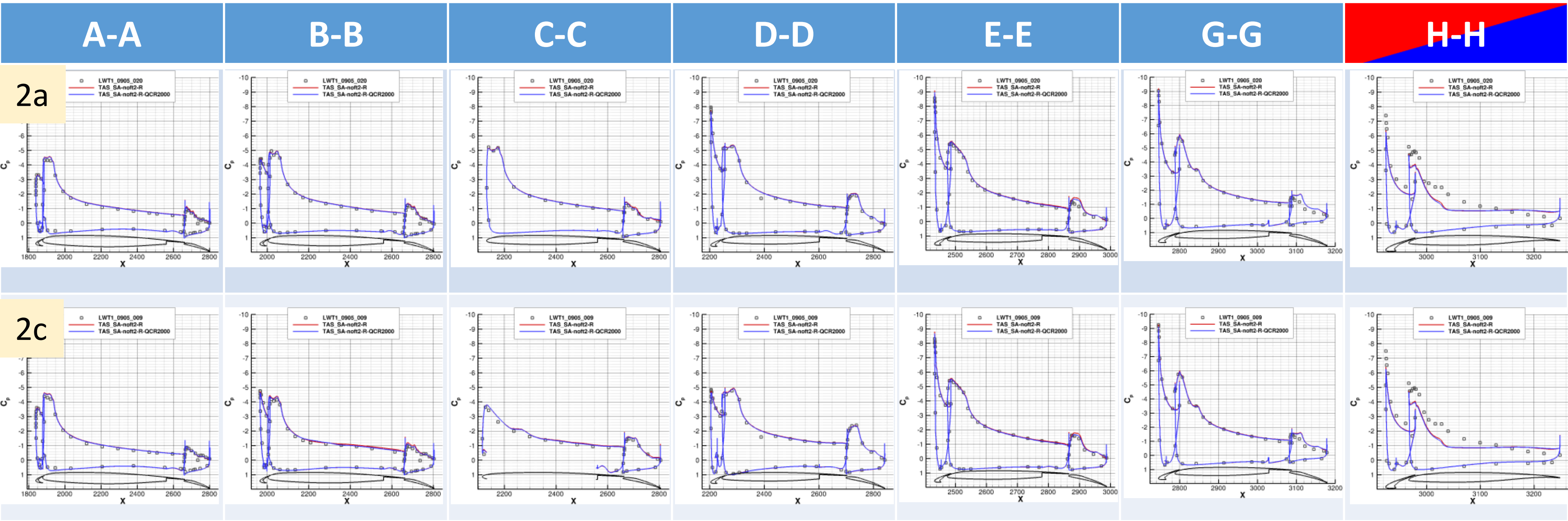
- Difference in the size of flow separation between QCR on & off

Exp	QCR off	QCR on
Case 2a *No oil flow images available*		
Case 2c *No oil flow images available*		

Cases 2a & 2c – JSM C_p α = 18.58°

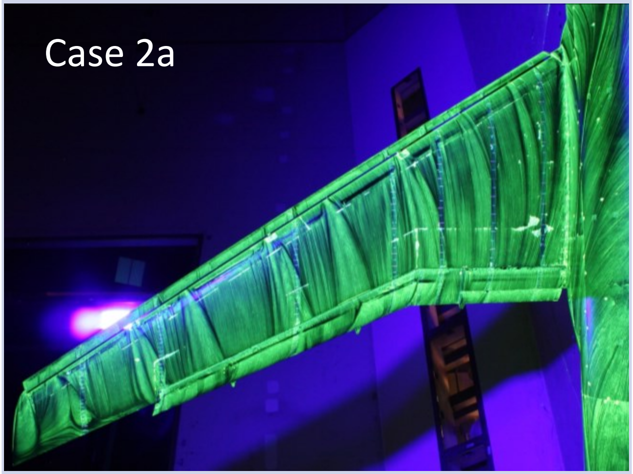
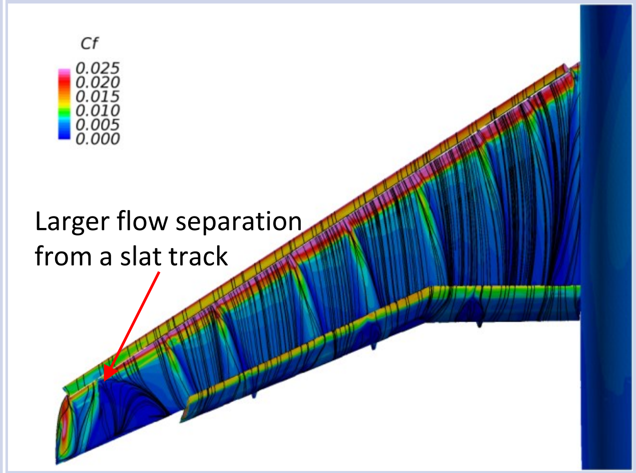
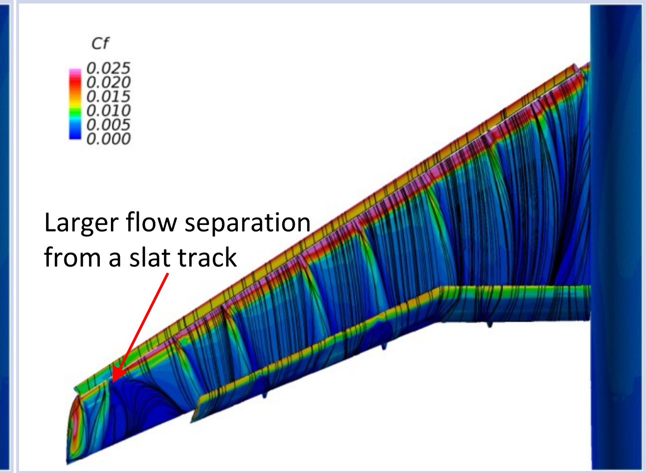
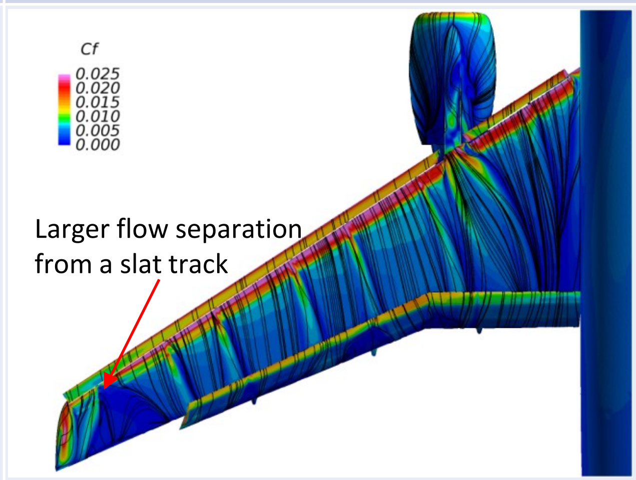
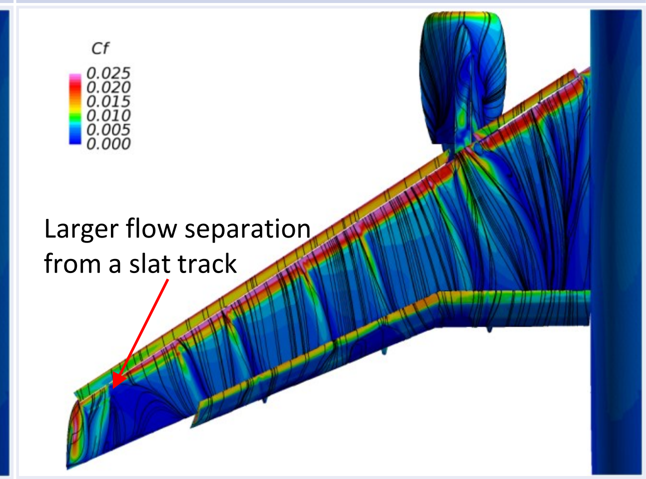
- QCR on/off predict similar Cp distributions and large flow separation at H-H section, which was not observed in the experiment.

QCR off
QCR on



Cases 2a & 2c – JSM α = 18.58°

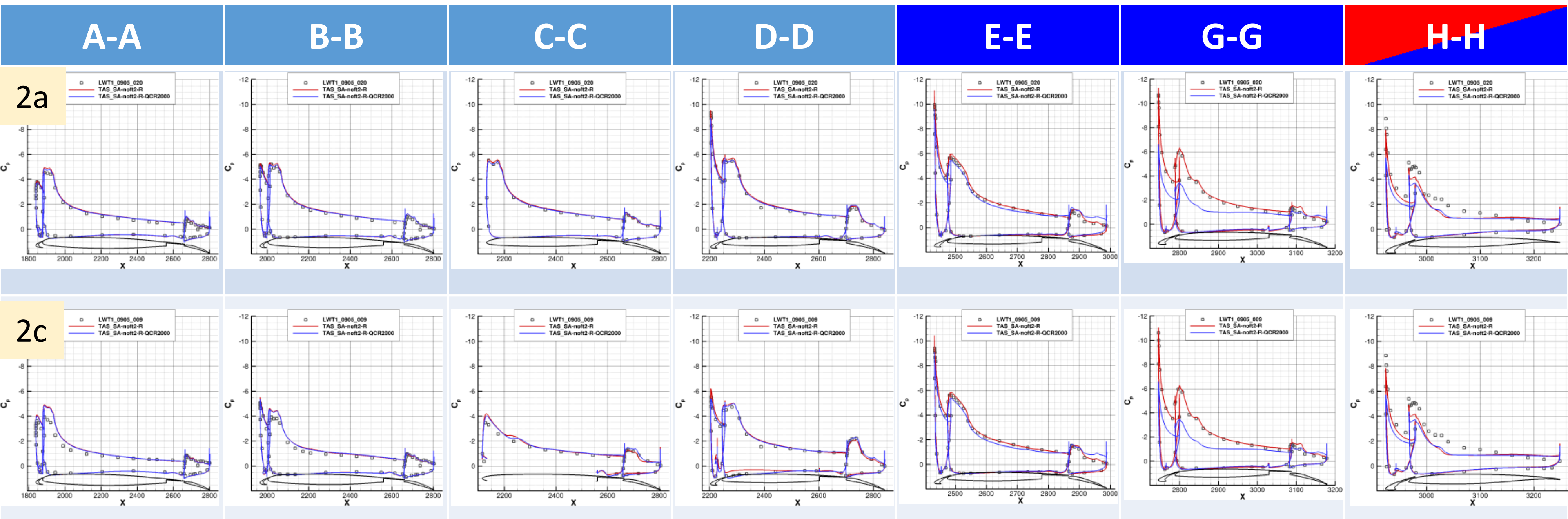
- Difference in the size of flow separation between CFD & WTT

Exp	QCR off	QCR on
		
		

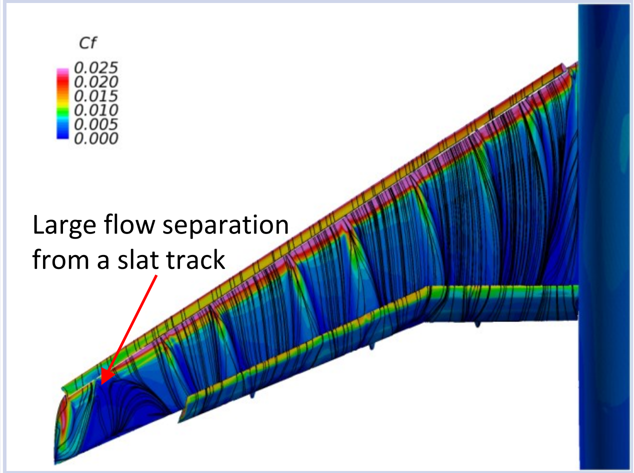
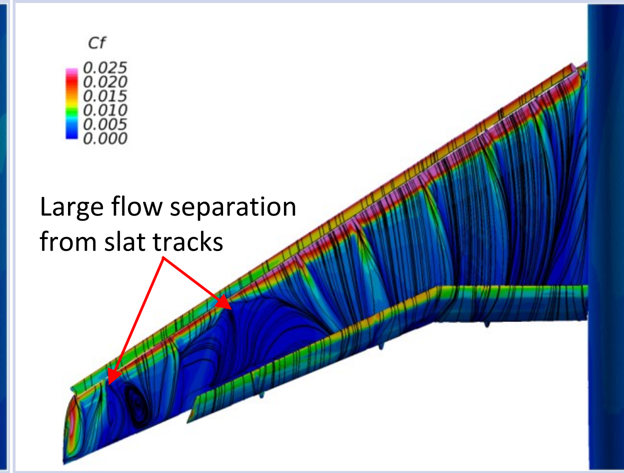
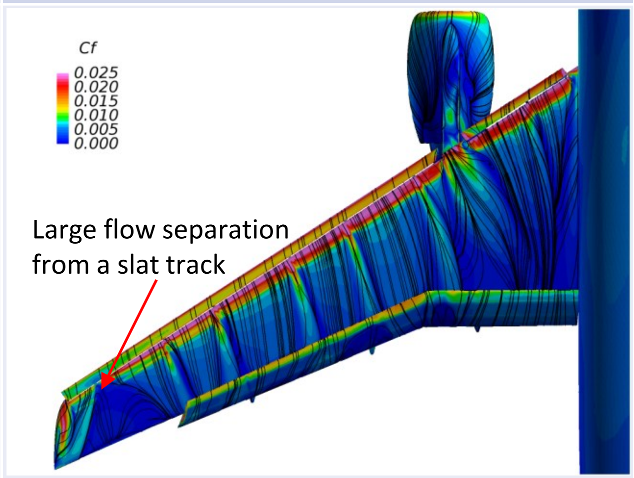
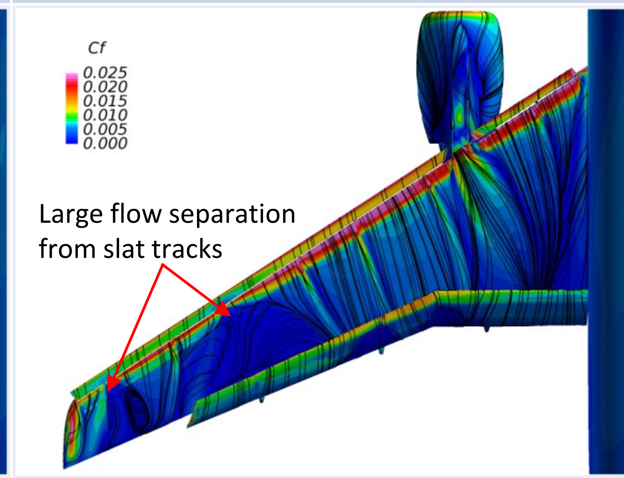
Cases 2a & 2c – JSM C_p $\alpha = 20.59°$

- QCR on predicts large flow separation on the outboard wing.
- QCR off also predicts large flow separation at H-H section.

QCR off
QCR on



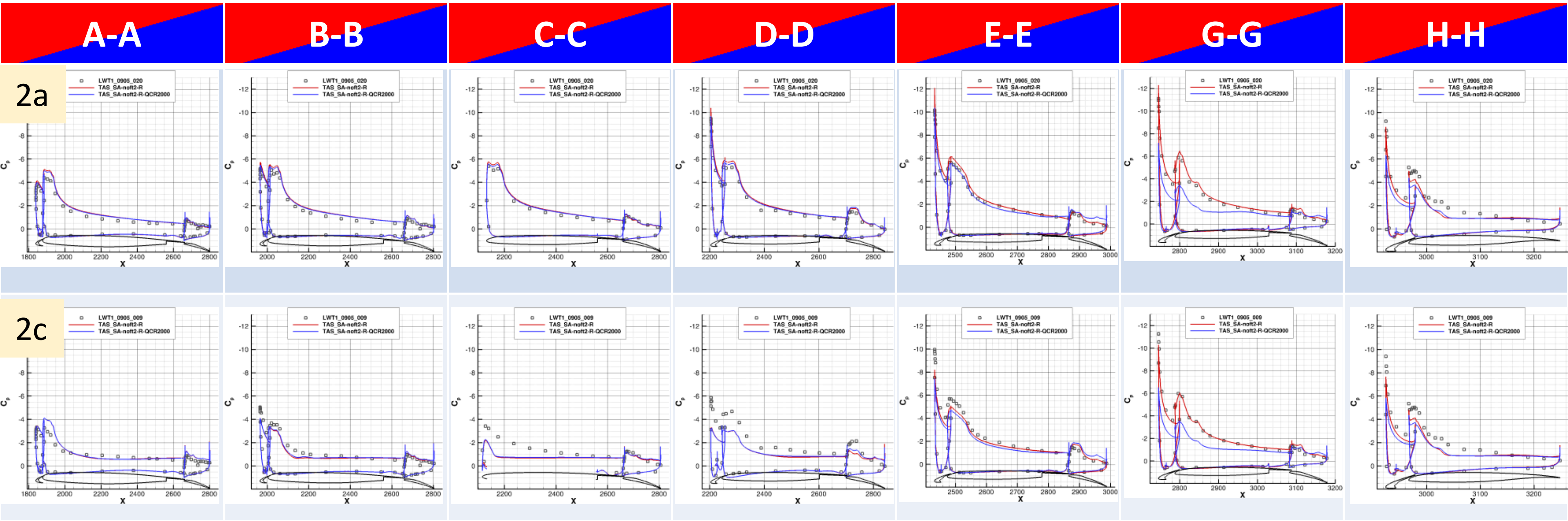
Cases 2a & 2c – JSM α = 20.59°

Exp	QCR off	QCR on
Case 2a *No oil flow images available*		
Case 2c *No oil flow images available*		

Cases 2a & 2c – JSM C_p $\alpha = 21.57°$

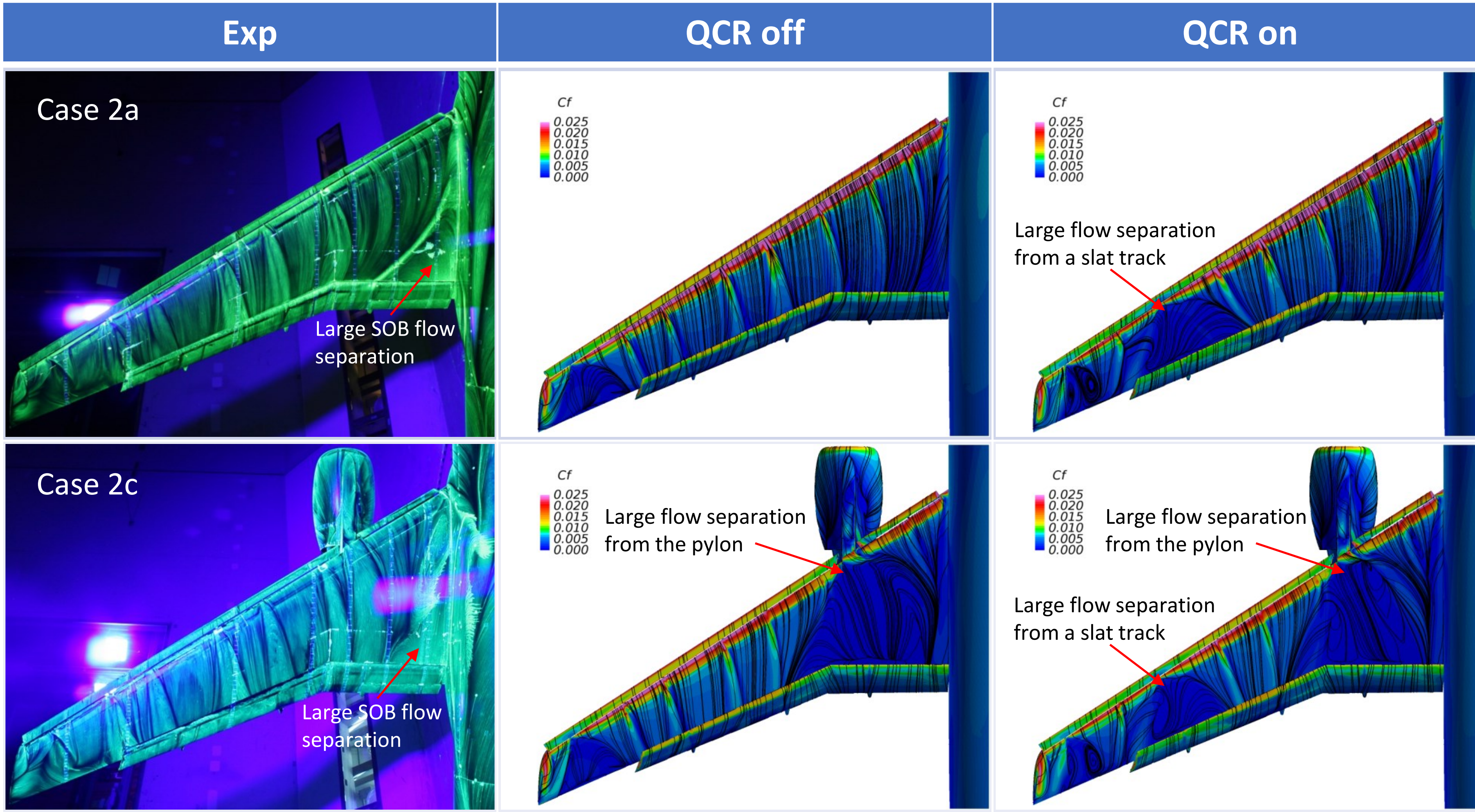
- QCR on/off predict slightly different Cp distributions even at inboard sections.
- QCR off predicts better Cp distribution at G-G section.

QCR off
QCR on



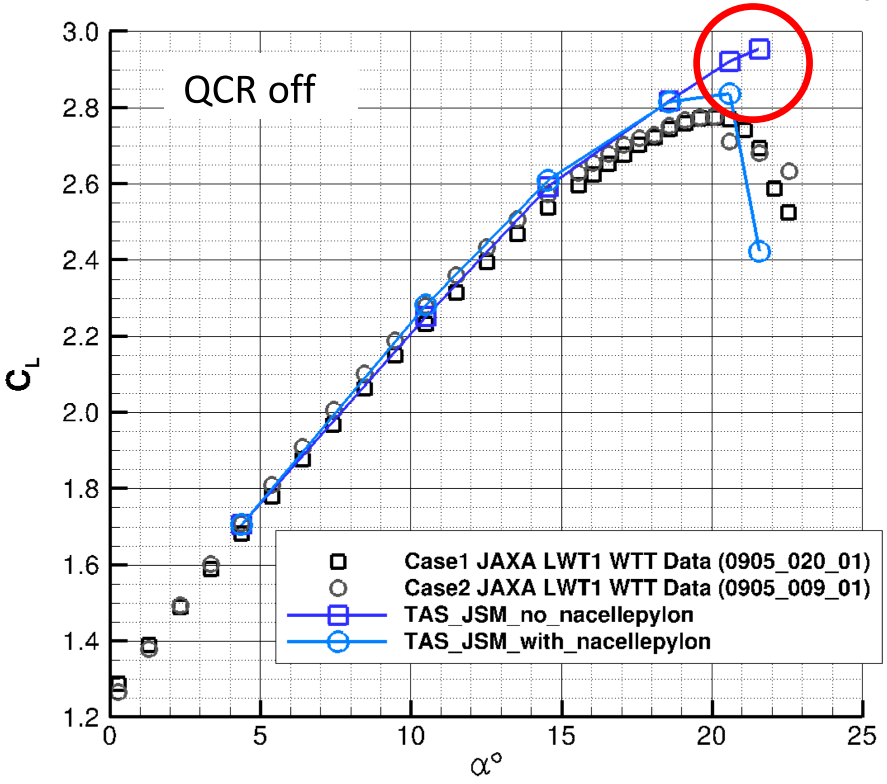
Cases 2a & 2c – JSM α = 21.57°

- Difference in the size of flow separation between CFD & WTT



Case 2a JSM C_L-α

- QCR off agreed better with experiment in Cases 2a & 2c.
- QCR off predicted higher $C_{L\max}$ with the JAXA medium grid.
  - Does the laminar-to-turbulent transition need to be considered?
    - JAXA has provided the info.
  - Does wing deformation influence the prediction?
  - How about the mesh density?



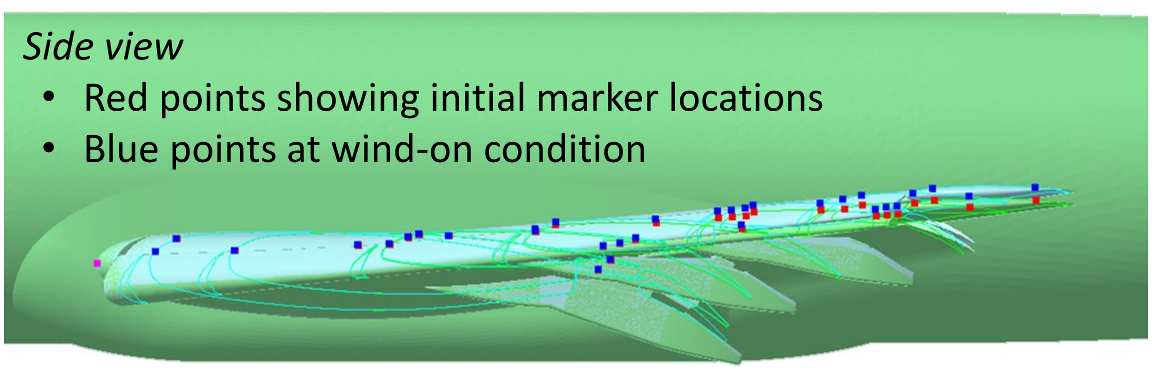
Case 2a JSM Wing Deformation for Meshes

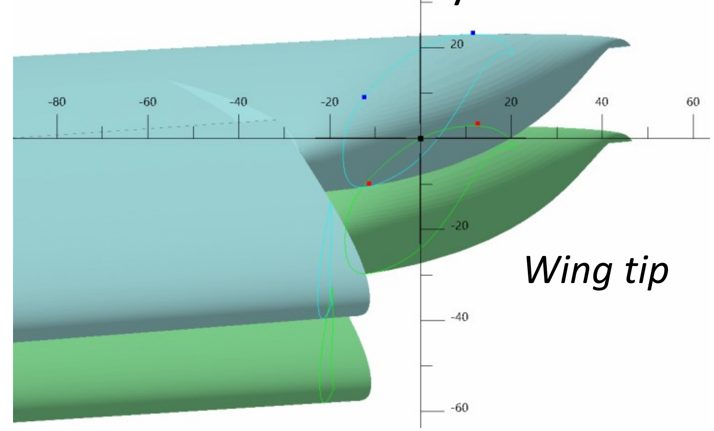
- Polynomial approximation using displacement data measured at 32 markers on the main wing element in a wind tunnel test.
  - Quartic approximation to estimate wing bending and twisting
    - Yasue, K. and Ueno, M., “Model Deformation Corrections of NASA Common Research Model Using Computational Fluid Dynamics,” *Journal of Aircraft*, Vol. 53, No. 4, July 2016, pp. 951-961, DOI: 10.2514/1.c033445.
    - Le Sant, Y. “A Model Deformation Method Applied to PSP Measurements,” Proceedings of the 20th International Congress on Instrumentation in Aerospace Simulation Facilities, 2003.

    $x_d = x_a, y_d = y_a,$

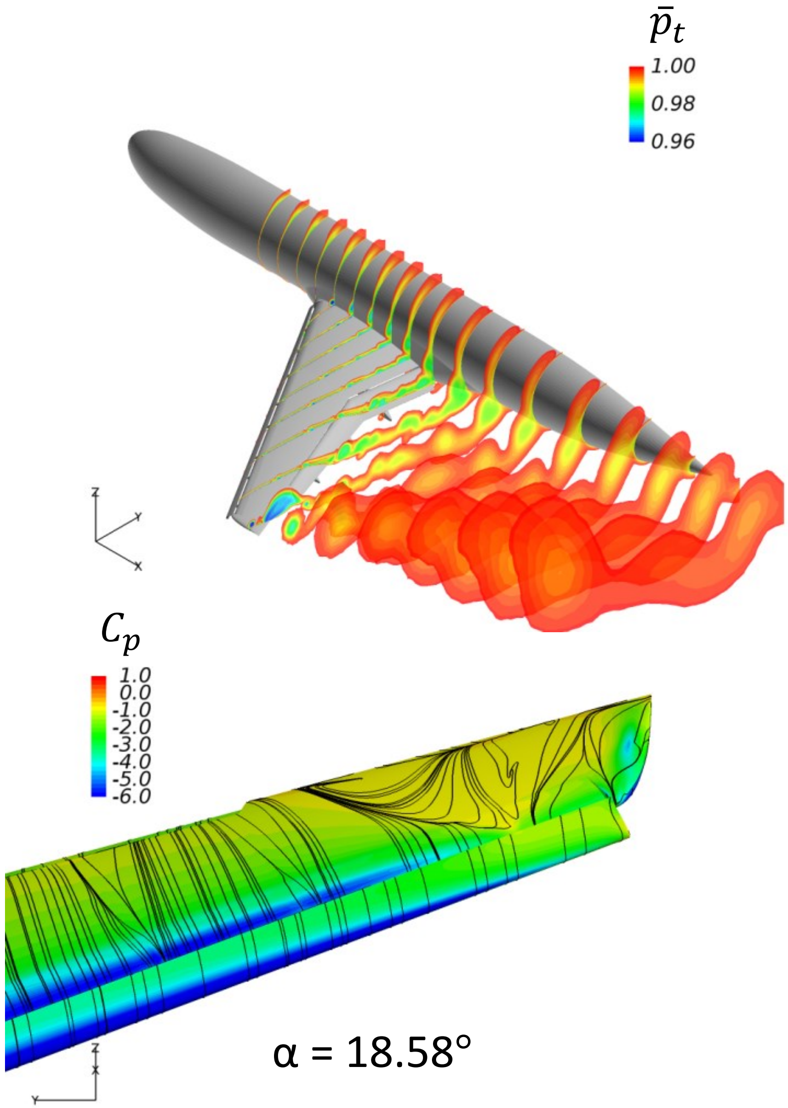
    $z_d = z_a + y_a^2 o_2 + y_a^3 o_3 + y_a^4 o_4 + x_a y_a t_1 + x_a y_a^2 t_2 + x_a y_a^3 t_3 + x_a y_a^4 t_4$

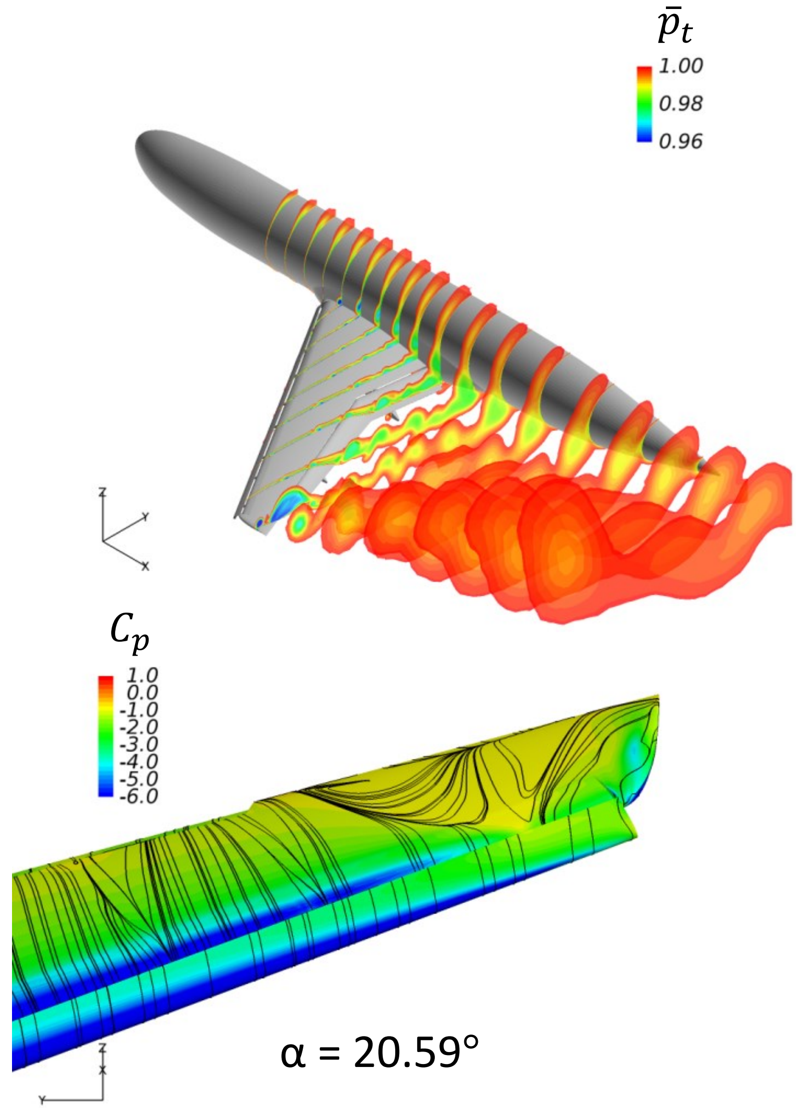
    $\mathbf{x}_a = (x_a, y_a, z_a)$ and $\mathbf{x}_d$ are in the coordinate system obtained by rotating the initial coordinate system around the *x*-axis by the wing dihedral angle, 3.0°.
  - Only *y* < -311.9 mm is deformed.
  - Gap, overlap and deflection angle of the slat and the flap are not changed.
  - Currently, Case 2a (nacelle/pylon off) using WTT data at α = 20° only.



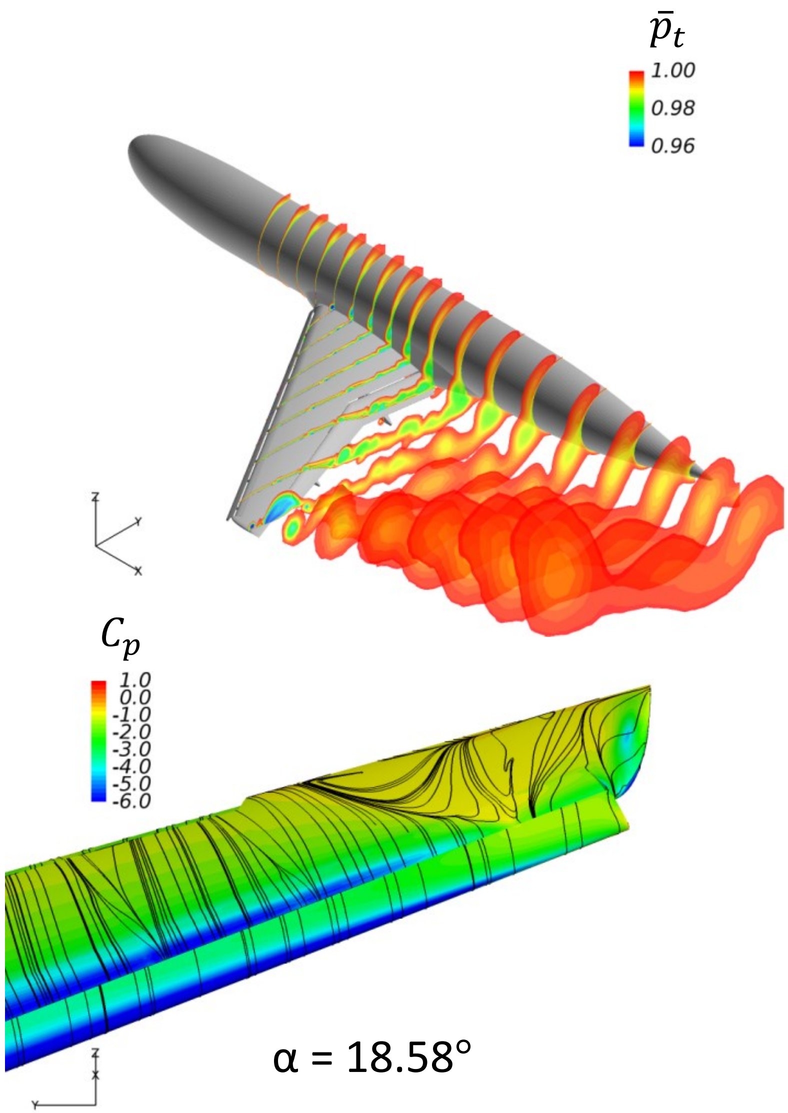


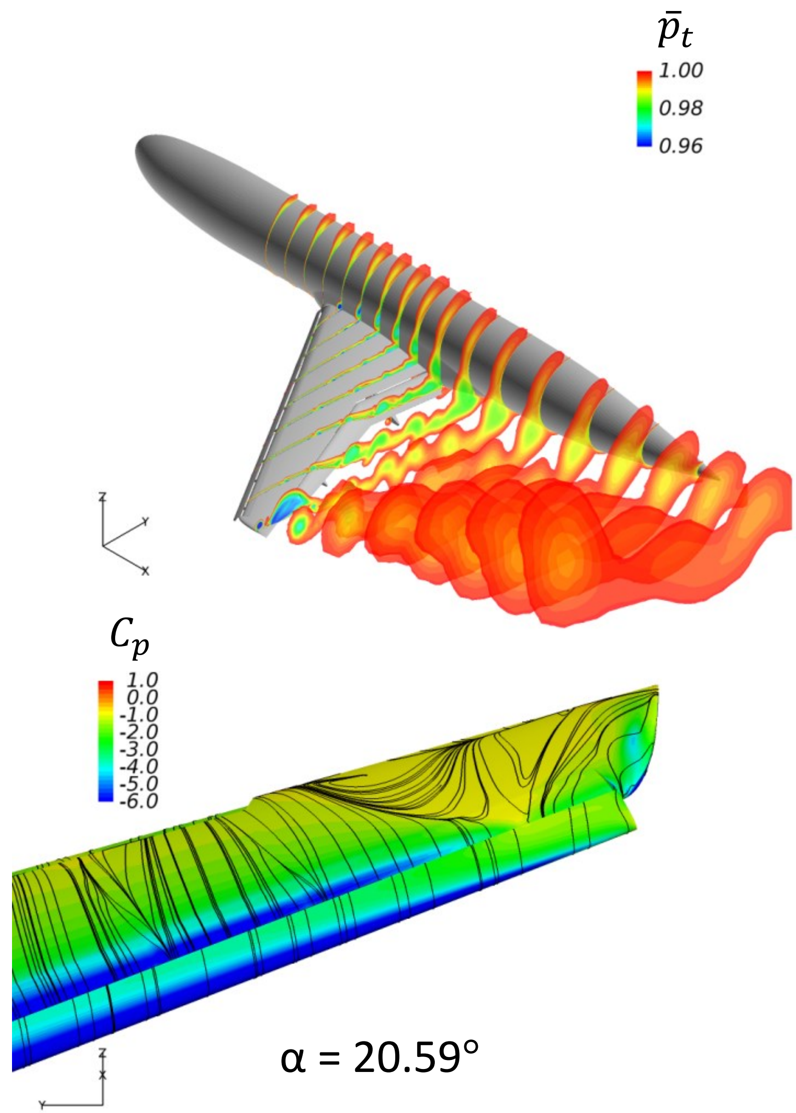
Case 2a JSM – No Wing Deformation





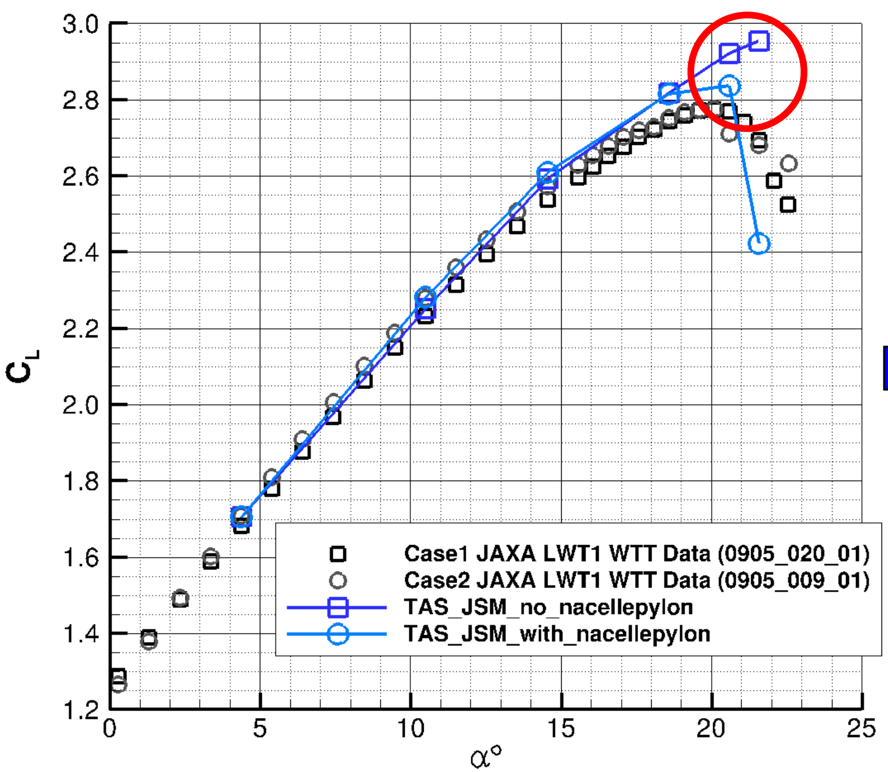
Case 2a JSM – Wing Deformation Applied

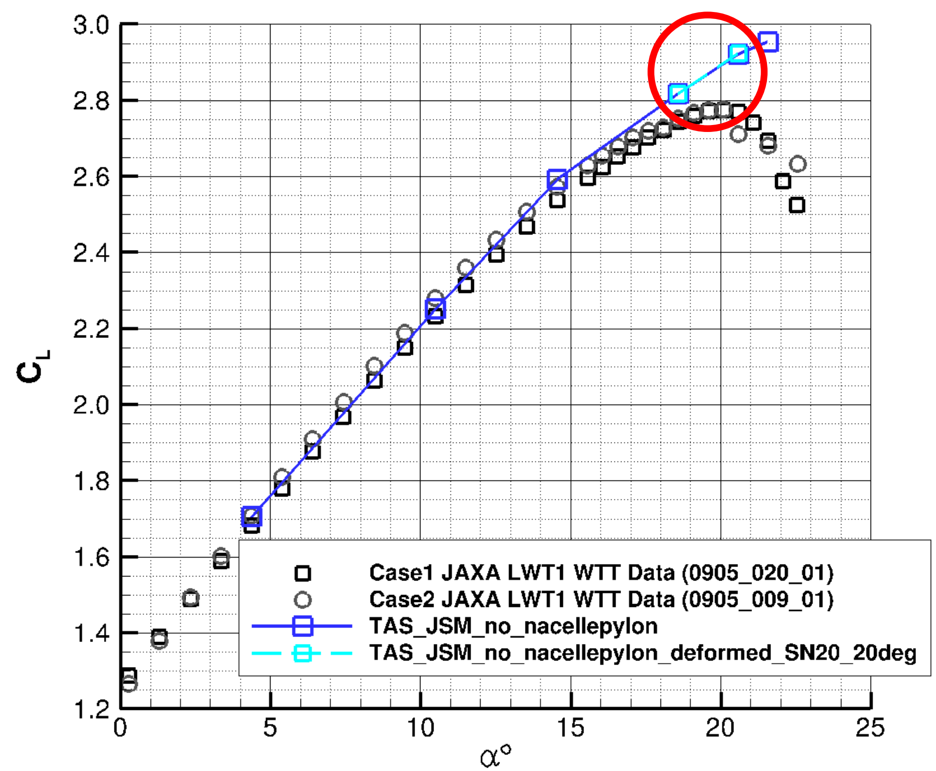




Case 2a JSM – C_L-α

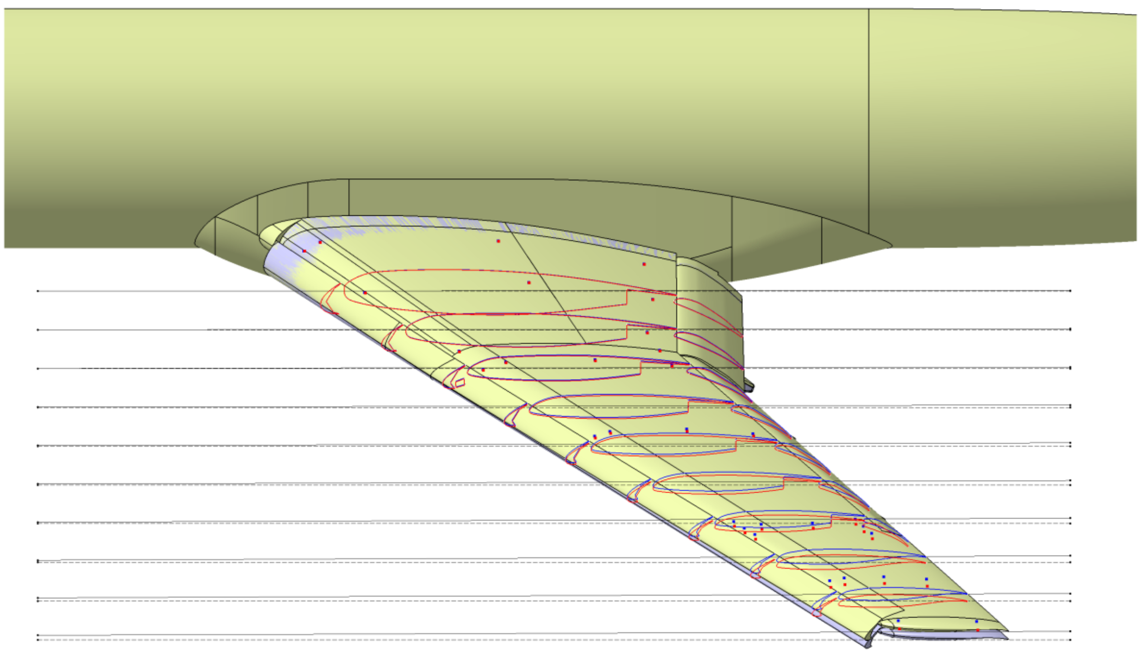
- TAS code predicted higher C_{Lmax} with JAXA medium grid.
- Does wing deformation influence the prediction?
  - No, according to TAS code with the medium grid for Case 2a.
  - Finer meshes are needed for further evaluation.





Cases 2a & 2c JSM Wing Deformation for CAD Model

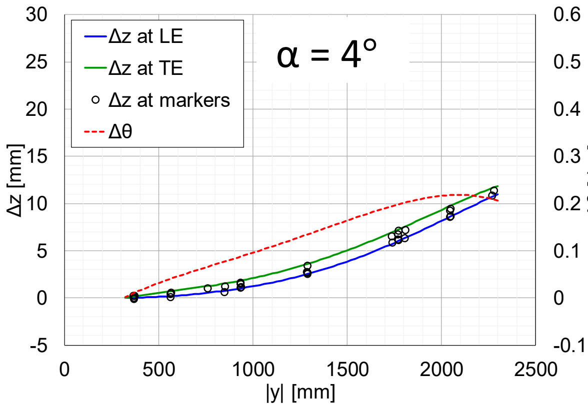
- The same polynomial approximation is applied to CAD models on CATIA by defining 10 sections on the wing reference plane (WRP).
  - Case 2a (nacelle/pylon off) at α = 4°, 10°, 14°, 20°, 21°
  - Case 2c (nacelle/pylon on) at α = 4°, 10°, 14°, 18°, 20°, 21°
- The deformed CAD models to be released for public.

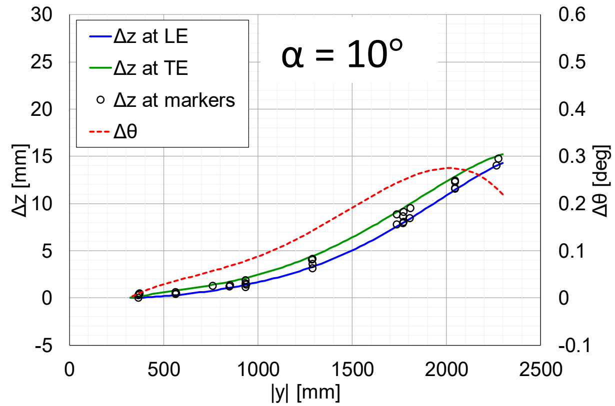


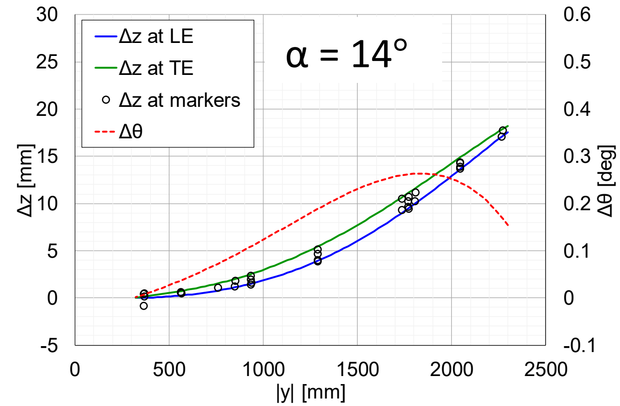
- Example: Case 2a at α = 21°
- Before deformation:
  - Black dashed lines on WRP & corresponding red sections
  - Red dots from a wind tunnel test as reference
- After deformation:
  - Black solid lines on WRP & corresponding blue sections
  - Blue dots from a wind tunnel test

Case 2a (nacelle/pylon off) JSM Deformed CAD Models

- Displacement in the *z* direction Δ*z* at the retracted wing leading and trailing edges and change in twist angle Δθ

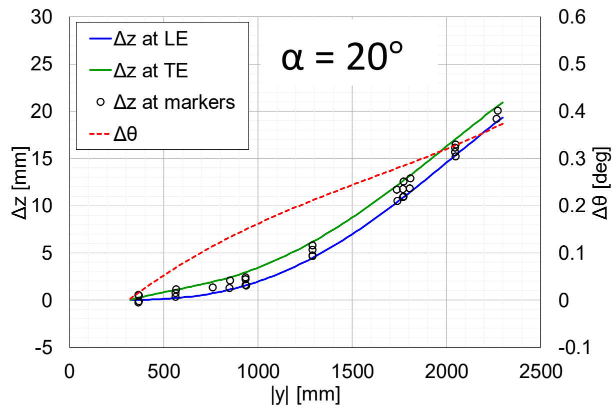


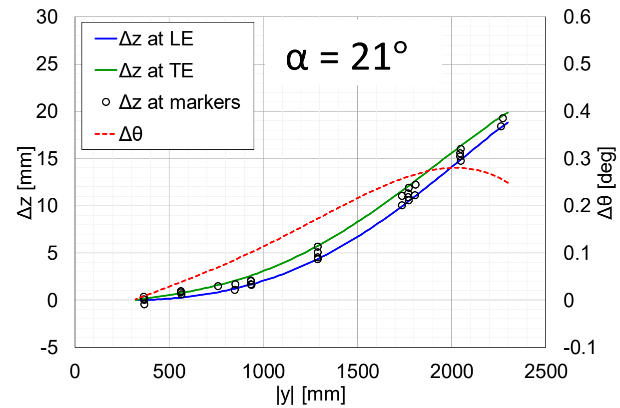




α = 18°

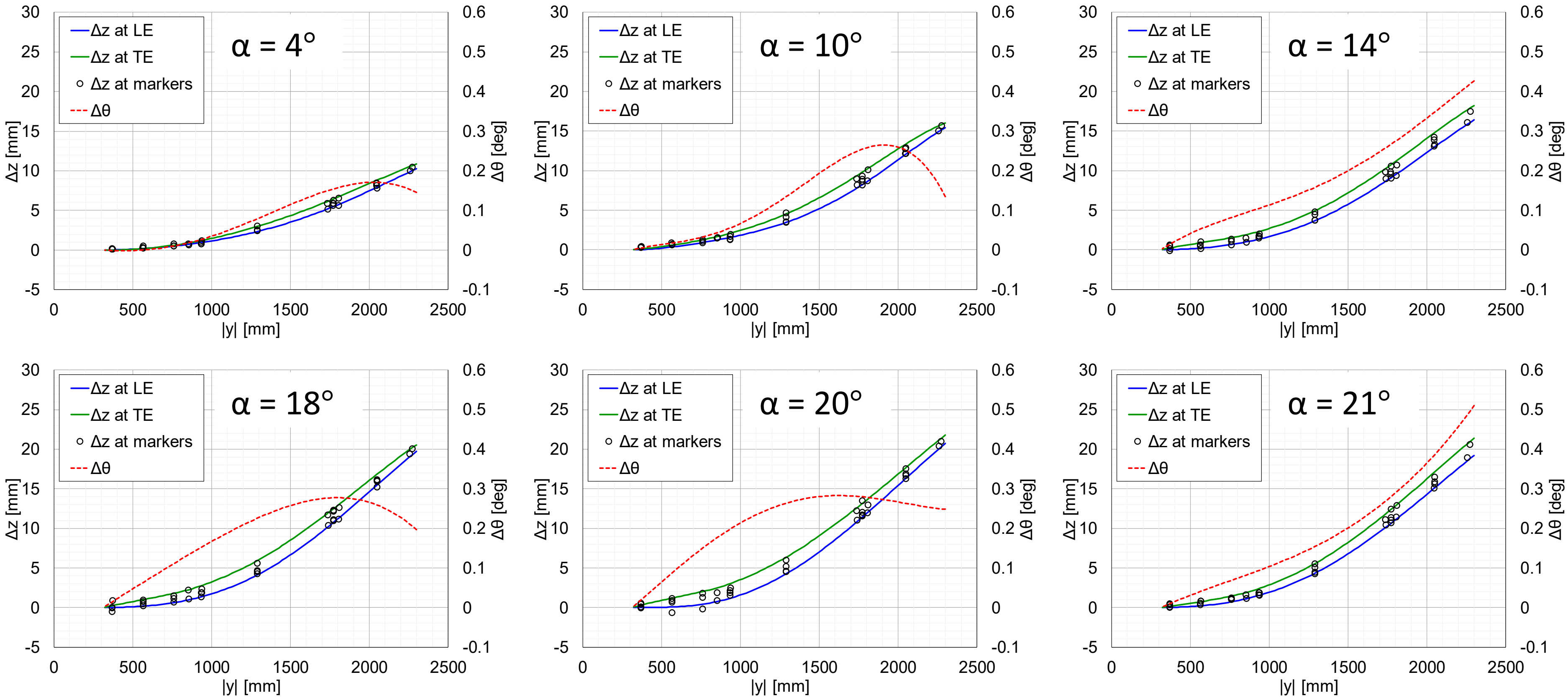
Not available





Case 2c (nacelle/pylon on) JSM Deformed CAD Models

- Displacement in the *z* direction Δ*z* at the retracted wing leading and trailing edges and change in twist angle Δθ



Summary

- Large flow separation was observed on the HL-CRM flaps, but with the B3 fine mesh, much smaller separation was observed at α = 16°.
- When QCR in the SA turbulence model is turned on,
  - Slightly larger flow separation was observed with HL-CRM and JSM, which was similar to the HiLiftPW-2 DLR F11 cases.
  - Large flow separation was observed from JSM slat tracks at high α.
- JSM wing without nacelle/pylon was deformed based on marker displacement measurements in a wind tunnel test at α = 20°.
  - No significant effect was observed in aerodynamic coefficients with the JAXA medium grid.
  - Cases 2a & 2c JSM CAD models were deformed at several angles of attack for public release, to be available on the HiLiftPW web site shortly.
  - The effect of mesh density needs to be evaluated.